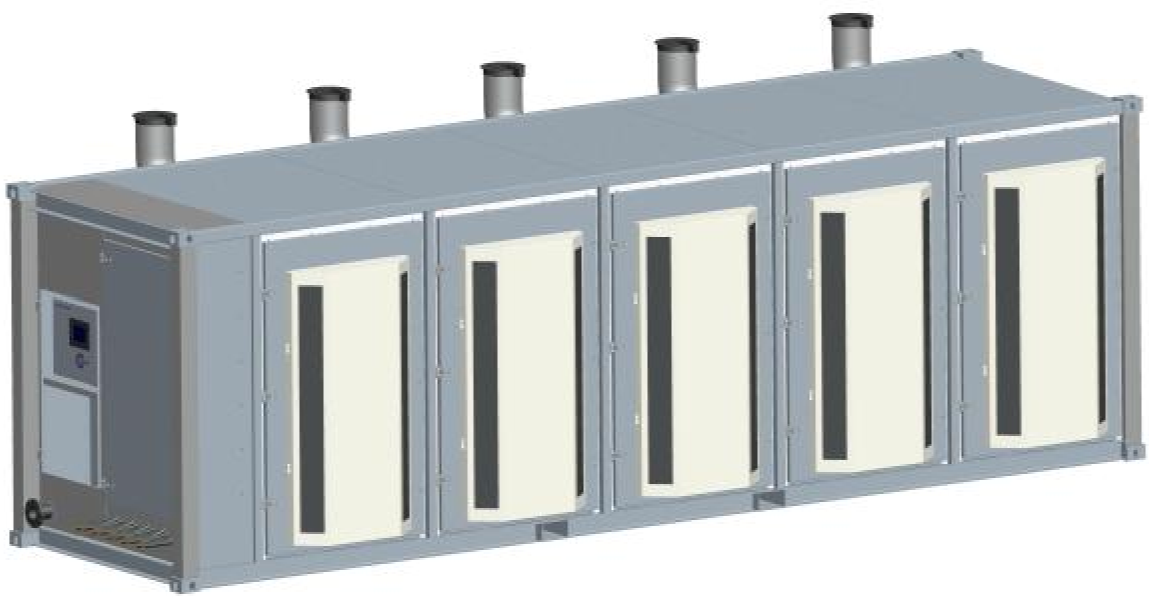
CAPSTONE TURBINE CORPORATION

CAPSTONE C1000 MICROTURBINE SYSTEMS

TECHNICAL REFERENCE



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CHAPTER 1: INTRODUCTION

Document Overview

This document is intended to give the reader a general description of the C1000 Capstone MicroTurbine® Systems, which consist of Models C600, C800 and C1000. It includes a description of the major components and how they interact, detailed product performance, and basic application guidance. It is intended to be used by a variety of audiences, and provides references to additional information which may be needed to answer more detailed questions. Within this document, you will find hyperlinks that will direct you to related topics in sections you are referencing. Clicking these links will move the document to that section.

Below are a few examples of how this technical reference may be useful to selected audiences:

Architects, Engineers, and other Equipment Specifiers

Capstone MicroTurbines are gas turbines with a variety of unique features compared with traditional forms of electric generation. This technical reference provides an overview of how the Capstone MicroTurbine system operates, along with detailed performance information. This information is intended to assist project specifiers and designers to properly select the best Capstone C1000 MicroTurbine system for a given application, and then complete a system design that includes the selected MicroTurbine(s). Other documents that may be relevant for this purpose are:

- C1000 Product Specification (460051) – This document summarizes the key performance characteristics of the C1000 MicroTurbine models, and is the basis for Capstone's standard warranty. The Product Specification information has precedence in the case of any conflict with this technical reference.
- C1000 Outline and Installation (O&I) Drawings (524341) – Detailed dimensions, weights, and other product installation information are contained in this document. The O&I drawings take precedence in case of any conflict with this technical reference.
- Fuel Requirements Technical Reference (410002) – The fuel requirements document provides detailed information about fuel characteristics required for proper operation of any Capstone MicroTurbine.
- Emissions Technical Reference (410065) – The emissions for all Capstone distributed generation products are summarized in this technical reference to address local air permitting requirements.

Capstone MicroTurbine Owners and Operators

Owners and operators may find the technical information in this document useful to understand the basics of how their Capstone C1000 MicroTurbine system operates. Capstone MicroTurbines are gas turbines with a variety of unique features compared with traditional forms of electric generation. This document provides information that will properly set performance and behavior expectations of the C1000 MicroTurbine system. Other documents that may be relevant for this purpose are:

- C1000 User's Manual (400024) – The C1000 User's Manual provides explanations of how to interact with the C1000 MicroTurbine models (including details of the local user display), as well as general maintenance guidance and simple troubleshooting.
- CRMS-APS Technical Reference User Edition (410074) – The user edition the Capstone Remote Monitoring Software for the Advanced Power Server (CRMS-APS) provides more detailed information for working with the C1000 packages than through the C1000 Controller's graphic user interface alone. The CRMS-APS User Edition explains how to operate this optional software.
- C1000 Product Specification (460051) – This document summarizes the key performance characteristics of the C1000 MicroTurbine models, and is the basis for Capstone's standard warranty. The Product Specification information has precedence in the case of any conflict with this technical reference.

Capstone Installers and Service Personnel

The C1000 Technical Reference is intended to be a "hub" from which installers and service technicians can find all relevant technical details regarding the troubleshooting, installation, sizing, and interconnection of the equipment. Other documents that may be relevant for this purpose are:

- C1000 O&I Drawings (524341) – Detailed dimensions, weights, and other product installation information are contained in this document. The O&I drawings take precedence in case of any conflict with this technical reference.
- Fuel Requirements Technical Reference (410002) – The fuel requirements document provides detailed information about fuel characteristics required for proper operation of any Capstone MicroTurbine.
- CRMS-APS Technical Reference Maintenance Edition (410073) – The service edition of the Capstone Remote Monitoring Software for the Advanced Power Server (CRMS-APS) provides more detailed information for working with the C1000 packages than through the C1000 Controller's graphic user interface alone. The CRMS-APS Maintenance Edition explains how to operate this service software.
- C1000 Troubleshooting Guide (430073) – This document provides detailed descriptions of troubleshooting codes and suggested actions to resolve problems.

CHAPTER 2: PRODUCT OVERVIEW

The Capstone C1000 Series MicroTurbines are adaptable, low-emission, and low maintenance power generation systems. The C1000 Series combines multiple turbine-driven high-speed generators with digital power electronics to produce a single high quality electrical power output.

The Capstone C1000 MicroTurbine product is modular and built around a number of 200 kW power modules, the number of power modules used can be determined from the model number or the nominal power output; 3 are used in the C600, 4 in the C800 and 5 in the C1000. The C600 and C800 models can be upgraded to higher power outputs in increments of 200 kW with the addition of Capstone C200 power modules. The general term C1000 MicroTurbine system includes all three models; most attributes of the MicroTurbine package other than power output are identical across all models. A clear distinction will be made in this document when system performance differs between models.

The Capstone MicroTurbine is a versatile power generation system suitable for a wide range of applications. Capstone's proprietary design allows users to optimize energy costs while operating in parallel with an electric utility grid. The Alternating Current (AC) electrical power output from the MicroTurbine can be paralleled with an electric utility grid or with another generation source. The MicroTurbine can act as a Stand Alone generator for standby, backup, or remote off-grid power. Multiple systems can be combined and controlled as a single larger power source, called a MultiPac.

The MicroTurbine can efficiently use a wide range of approved hydrocarbon-based gaseous fuels. The MicroTurbine produces dry, oxygen-rich exhaust with ultra-low emissions. Utilizing both the generated electric power and the exhaust heat can provide even greater energy cost savings.

Key Components

The Capstone C1000 MicroTurbine systems consist of three (C600), four (C800) or five (C1000) power modules installed in one compact 30 foot ISO-style container. The C1000 and its constituent power modules are shown in Figure 2-1.

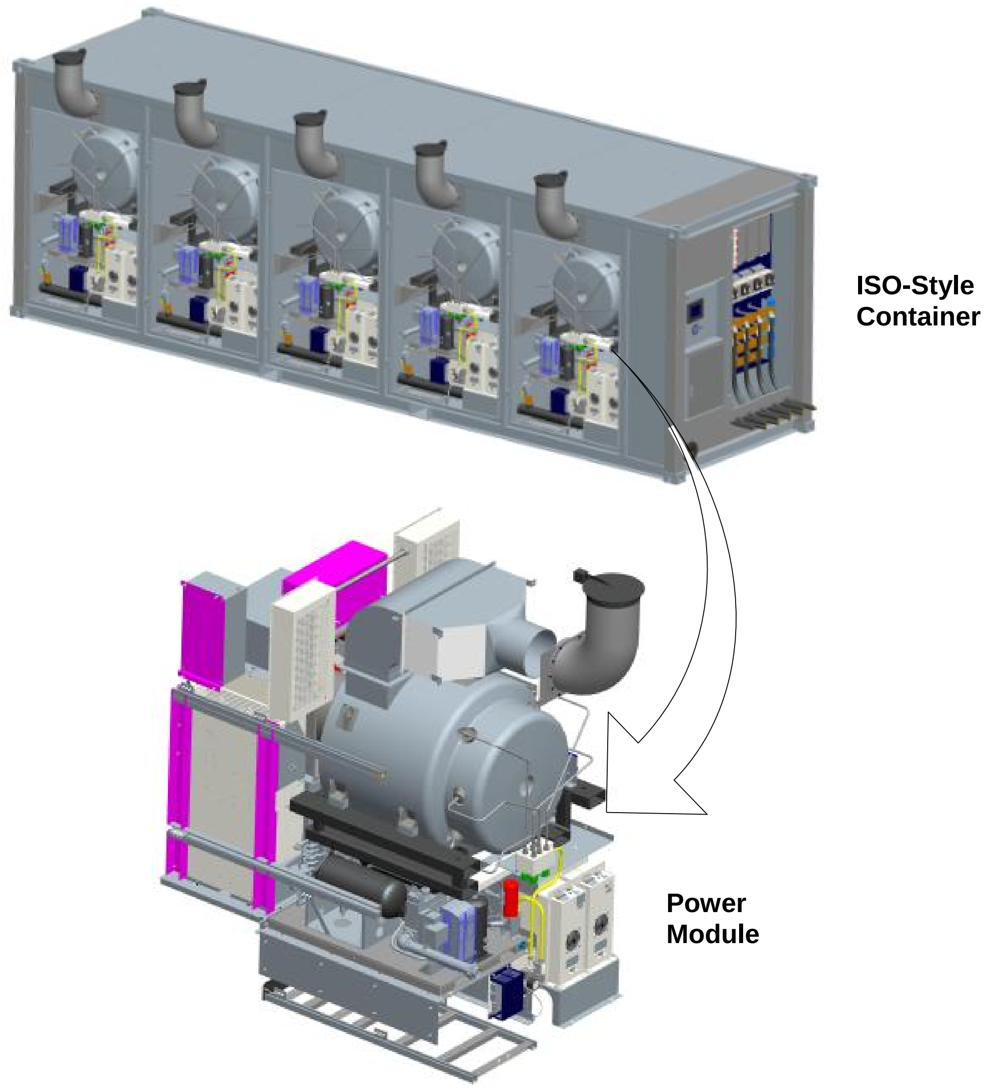


Figure 2-1. C1000 Series Power Modules

Each power module used in the C1000 MicroTurbine systems consists of the following key components: fuel system, MicroTurbine generator, power electronics and batteries (for Dual Mode systems). Figure 2-2 details the Capstone MicroTurbine and generator.

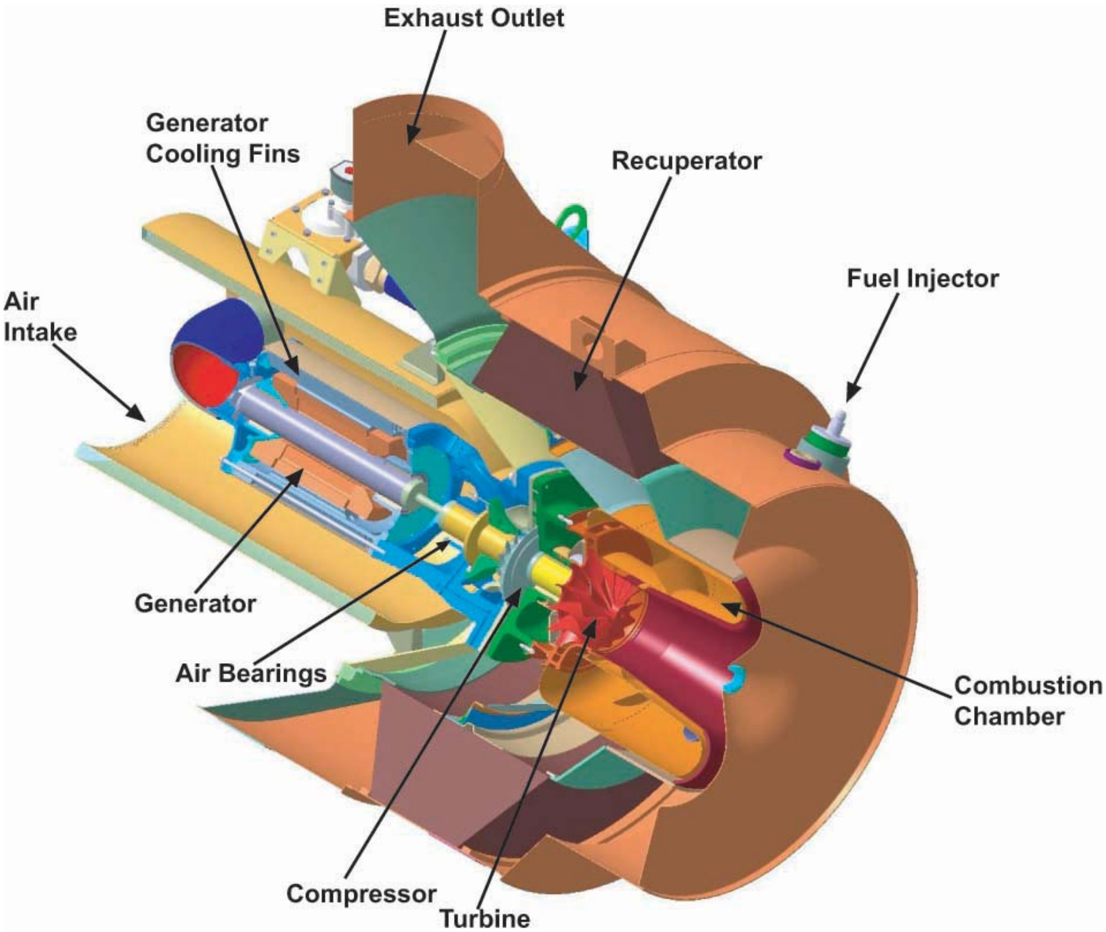


Figure 2-2. Typical Capstone C200 Turbogenerator Construction

Main Features

The main features of the Capstone C1000 MicroTurbine systems are:

- Reliable, clean, maintenance-free generation of 600 kilowatts to 1 Megawatt of power. Clean, useable waste heat is available for cogeneration applications.
- Intelligent system controller with high efficiency modes, smart load following capabilities and engine run time balance for better routine maintenance planning.
- Power module designs provides inherently redundant configuration for outstanding availability.
- C600 and C800 systems can be upgraded to 1 Megawatt in 200 kilowatt increments with an easy field retrofit kit.

The main features of the Capstone 200 kW power modules are:

- A state-of-the-art digital power controller with built-in protective relay functions provides two output choices:
  - Built-in synchronous AC
  - Stand Alone AC output (optional).
- Patented air bearings eliminate the need for oil or other liquid lubricants.
- Air-cooled design of the entire system (turbine and controller) eliminates the need for liquid coolants.
- Each 200 kW MicroTurbine engine has only one moving part: no gears, belts, or turbine-driven accessories.
- Advanced combustion control eliminates the need for ceramics or for other costly materials or for catalytic combustion, and provides ultra-low emissions.
- The integral annular recuperator (heat exchanger) doubles electrical efficiency.
- Digital control technology facilitates advanced control or monitoring, and diagnostic capabilities, both on-board and remotely.

Air Bearings

The MicroTurbine utilizes air foil bearings (air bearings) for high reliability, low maintenance, and safe operation. This allows fewer parts and the absence of any liquid lubrication to support the rotating group. When the MicroTurbine is in operation, a film of air separates the shaft from the bearings and protects them from wear.

Emissions

The Capstone MicroTurbine is designed to produce very clean emissions. The exhaust is clean and oxygen rich (approximately 18% O_2) with very low levels of air pollutants. Like all fuel combustion technology, the MicroTurbine produces emissions (like nitrogen dioxide and carbon monoxide) from the fuel combustion process. The MicroTurbine has ultra low nitrogen dioxide (NO_2) and carbon monoxide (CO) emission levels. Refer to the Capstone Emissions Technical Reference (410065) for details.

Enclosure

The C1000 MicroTurbine systems are available with two enclosure types. The enclosures are suitable for outdoor installation and the units are stackable. The outside dimensions of all C1000 MicroTurbine systems are approximately 30 feet long, 8 feet wide and 9.5 feet high. The differences between the standard and high humidity packages are detailed in Table 2-1.

Table 2-1. C1000 Series Enclosure Specifications

	Wind Loading	Paint Spec	IBC Seismic	Condensation protection	Stacking
Standard	110 mph	Standard	Cat A-E; Class A-D	None	Yes
High Humidity	156 mph	Marine	Cat A-F (no stack), Cat A-E (stacked); Class A-D	Greased, Heated Electronics	Yes (reduces wind rating)

Dual Mode Option

A Dual Mode option is available for the MicroTurbine. This option allows the MicroTurbine to operate in Grid Connect mode while it is connected to an electric grid, and to operate in Stand Alone mode if it becomes disconnected from the grid. The Dual Mode option includes two battery packs within each power module for unassisted start and for transient electrical load management. The battery packs are lead-acid type, completely sealed and maintenance-free.

When operating in Stand Alone mode, the system can power connected loads at user-selected voltage and frequency setpoints. It can power remote facilities such as construction sites, oil fields, offshore platforms, and other locations where the electric utility grid is not available.

Distributed Generation

The MicroTurbine produces synchronous current when connected to an electric utility grid. It allows electric utilities to expand power generation capacity in small increments, to optimize current infrastructure, and reduce or delay the need to develop, fund, and build new transmission and distribution lines.

Heat Recovery Modules

Hot water Heat Recovery Modules (HRM) are available for use with the C600, C800 and C1000 MicroTurbine models. The HRM is an exhaust economizer with integral temperature setpoint controller and exhaust diverter. The controller provides digital readout of water temperature leaving the heat exchanger, and allows the user to set the desired outlet temperature. An electrically operated exhaust gas diverter valve is actuated by the controller to maintain outlet temperature to the selected setpoint. Power for the controller and actuator can be supplied by the auxiliary electrical output of the C1000 MicroTurbines packages.

C1000 MicroTurbine Applications

Capstone C1000 MicroTurbine models are commonly deployed for use in the following applications:

- Peak Shaving – The MicroTurbine system can augment utility supply during peak load periods, thus increasing power reliability and reducing or eliminating peak demand charges.
- Combined Peak Shaving and Standby – The MicroTurbine system can be used for both Grid Connect power and Stand Alone power for protected loads. With the Dual Mode System Controller (DMSC) accessory, the MicroTurbine can be programmed to switch automatically upon loss/restoration of electric utility grid power. The MicroTurbine, with its low emissions, low maintenance requirements, and high reliability is well suited for combination peak-shaving and standby power applications.
- MultiPac Power – Multiple Capstone MicroTurbines can be connected through the Advanced Power Server (APS) to achieve higher power outputs that operate as a single power generation source. Up to 20 Capstone C65 and C200 MicroTurbines can be connected along with up to 10 Capstone C1000 MicroTurbine packages for advanced control and dispatch of up to 14 Megawatts of MicroTurbine power generation. The Advanced Power Server allows the control of several groups of turbine power, each dispatched with their own control priorities. Complex control logic can be implemented to maximize the value of your turbine installation through integration of a utility power meter, building management system or programming time of day power set-points to offset variable electricity rates. More information is available in the Capstone Advanced Power Server User's Manual (400011). All MultiPac installations of the C1000 MicroTurbine product require the use of the Advanced Power Server.
- Resource Recovery – Capstone MicroTurbine models are available that use methane-based oilfield flare casing gas or low-energy landfill/digester gas as fuel sources. The C1000 Series is available in configurations that can accept Sour Gas with up to 5000 ppmV Hydrogen Sulfide (H_2S) content. This application helps reduce pollution and provides economical power for on-site use as a by-product.
- Thermal Heat Recovery – The oxygen-rich exhaust from the MicroTurbine can also be used for direct heat or as an air pre-heater for downstream burners. The optional C600, C800 and C1000 HRMs allow commercial businesses to offset or replace local thermal loads such as domestic hot water, space heating, pool heating, and industrial hot water. In addition, the oxygen-rich exhaust together with ultra-low emissions makes the direct exhaust applicable for some food processing and greenhouse uses, such as heating, cooling (by absorption), dehumidifying, baking, or drying.
- OEM Applications – The MicroTurbine core technology can be integrated into a wide variety of products and systems. Uninterruptible power supplies, all-in-one combined heat and power systems, and combined cooling, heat and power systems are some common OEM applications.

Output Measurements

The measurements presented in this document are mostly in metric units (with U.S. standard units in parentheses). Refer to the sections below for more data.

ISO Conditions

Combustion turbine powered devices (including the Capstone MicroTurbine) are typically rated at 15 °C (59 °F) at sea level, or 1 atmosphere (1 atm) which is 760 mm Hg (14.696 psia) and identified as International Organization for Standardization (ISO) conditions. For a complete definition of ISO testing conditions, refer to ISO 3977-2.

Pressure

Pressure figures assume gauge pressure, or 1 standard atmosphere (1 atm) 760 mm Hg (14.696 psia) less than absolute pressure, unless otherwise indicated.

Volume

Fuel gas and exhaust gas volumetric measurements are given in normalized cubic meters (m^3), defined at 0 °C (32 °F), and standard cubic feet (scf), defined at 15.6 °C (60 °F). Both volumes are defined at 1 atm (760 mm Hg, 14.696 psia).

Heating Values

Heat contents and heat rates will be found in either Lower Heating Value (LHV) (dry) or Higher Heating Value (HHV), depending upon the application. Capstone calculates heating values at 1 atmosphere (atm) and 15.6 °C (60 °F), according to ASTM D3588.

MicroTurbine Performance

The MicroTurbine electrical output capability is reduced when operating in higher ambient temperatures or elevations, and by intake or exhaust restrictions. Refer to Chapter 7: Performance in this document for details.

Grid Connect Output

The MicroTurbine electrical output in Grid Connect mode is 3-phase, 400 to 480 VAC and 45 to 65 Hz (both voltage and frequency are determined by the electric utility grid).

Allowable connection types include a 4-wire wye either solidly grounded or grounded through a resistor. For neutral ground resistor requirements refer to CHAPTER 8: Electrical Ratings - Grid Connect.

Stand Alone Output

When equipped with the Stand Alone option, the electrical output is user-adjustable from 150 to 480 VAC and from 45 to 60 Hz.

The output power need not be balanced. Loads can be connected 3-phases or single phase and phase-to-phase or phase-to-neutral, so long as the current limits of each phase are respected. A Ramp Start feature can assist in starting single/individual loads with large in-rush currents. Refer to CHAPTER 8: Electrical Ratings - Stand Alone in this document for more details.

Power Quality

The MicroTurbine output conforms to IEEE 519-1992, IEEE Recommended Practices, and Requirements for Harmonic Control in Electrical Power Systems. Refer to CHAPTER 8: Electrical Ratings in this document for more details.

Heat Output

The recuperated MicroTurbine can produce the following amounts of clean, usable exhaust heat in the range of 232 to 310 °C (450 to 590 °F). Each power module includes one exhaust stream of 305 mm (12 in) in diameter flowing up to 62 normal m^3 (2300 scf) per minute. These exhaust streams can be manifolded in any combination as required by the specific application. Table 2-2 shows the values for total available exhaust heat when all constituent power modules are manifolded together. Refer to CHAPTER 7: Performance in this document for more details.

Table 2-2. Exhaust Output Ratings

Parameter	C600	C800	C1000
Nominal Total Exhaust Energy	4,260,000 kJ/hr (4,050,000 Btu/hr)	5,680,000 kJ/hr (5,400,000 Btu/hr)	7,100,000 kJ/hr (6,750,000 Btu/hr)
Exhaust Mass Flow	3.99 kg/s (8.79 lbm/s)	5.32 kg/s (11.72 lbm/s)	6.65 kg/s (14.65 lbm/s)

Maintenance

C1000 MicroTurbine power systems require little maintenance beyond periodic intake air filter inspections. The use of air bearings, coupled with the fact that the MicroTurbine system does not incorporate a mechanical transmission, means that no lubricants or coolants are used. There is no periodic replacement and disposal of lubricants or filters and no associated inspection or monitoring requirements. Dual Mode systems use sealed lead acid batteries which also require no maintenance through their expected life. Refer to Chapter 11: Maintenance in this document for more information.

Certifications, Permits, and Codes

The Capstone C1000 MicroTurbine systems are designed and manufactured in accordance with a variety of national and international standards, including Underwriters Laboratories (UL), the American National Standards Institute (ANSI), European Norms (EN), the Institute of Electrical and Electronic Engineers (IEEE), and the California Air Resources Board (CARB). For detailed information on the requirements of each authority having jurisdiction and how the Capstone MicroTurbine meets those requirements, contact your Capstone Authorized Service Provider for assistance and the latest Capstone MicroTurbine Compliance List.

CHAPTER 3: SYSTEM DESCRIPTION

Overview

There are three models available in the C1000 MicroTurbine series, each with a different nominal power output: the C600 (600 kilowatts), the C800 (800 kilowatts), and the C1000 (1 Megawatt). Each MicroTurbine model is a system of gas turbine generator sets that provide electric power and clean process heat. The C1000 Series MicroTurbine is a fully integrated product that uses advanced solid-state power electronics to produce utility grade 3-phase electrical power at 400/480 VAC and 50/60 Hz.

The integrated microelectronic controllers synchronize with the electric utility and provide utility protection, thereby eliminating the need for additional third party protective equipment.

The C1000 series is built around the Capstone 200 kW MicroTurbine generator system. The C600 uses three of these power modules to total 600 kilowatts, the C800 uses four and the C1000 uses five. The use of 200 kW power modules in the C1000 series allows the C600 and C800 products to be upgraded to higher electrical power outputs with the addition of 200 kW power modules and provides opportunities for redundancy in all models.

The 200 kW power module and the individually packaged Capstone C200 are based on the same proven architectural concepts as the Capstone Model C65 MicroTurbine. The proven performance and reliability of the Capstone C65 over its tens of millions of hours of operation where used as the basis for a C200 design. The C200 has an extremely high power density due to the high rotational speed of its permanent magnet generator.

Just as the C65 and C200, the C1000 products have high electrical efficiencies for a turbine because it incorporates an air to air heat exchanger, called a recuperator. By recovering exhaust waste heat, and using it to pre-heat combustion air, the recuperator reduces the amount of fuel consumed by a factor of two. The C1000 packages also use inverter based power electronics, ensuring the highest quality power output and the safest grid interconnects.

Major C1000 Functional Elements

The major functional elements that make up the Capstone C1000 MicroTurbine systems and their constituent power modules are shown in Figure 3-1 and Figure 3-2.

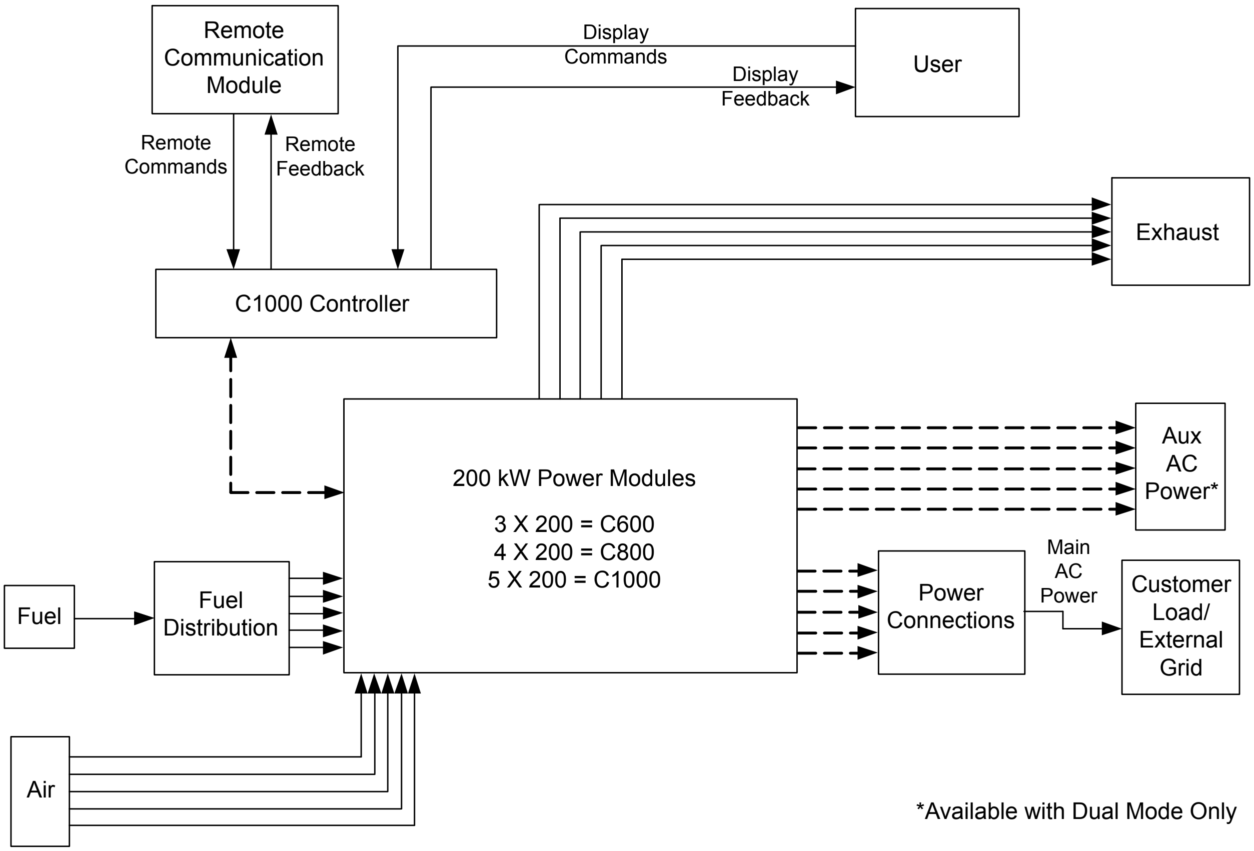


Figure 3-1. Major C1000 Functional Elements

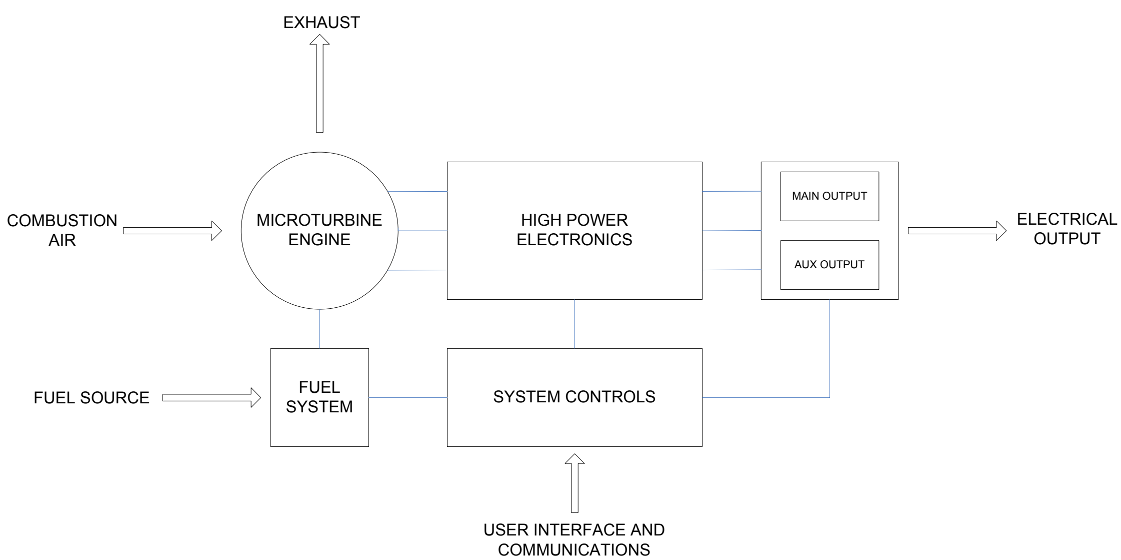


Figure 3-2. Major Power Module Functional Elements

C1000 Container

Each C1000 MicroTurbine generator system is housed in a 30-foot long container with five compartments. Three, four or five of these compartments are populated with 200 kW generator modules, depending on the model purchased. As previously stated, the 600 kW C600 model uses three 200 kW modules, the C800 uses four, and the C1000 uses five.

Every container, for all C1000 models, has the same exterior dimensions, regardless of the number of power modules installed in the container's five compartments. This leaves two empty modules on the C600 and one empty module on the C800. At a later time these empty compartments can be field retrofitted with a 200 kW power module if higher system power outputs or redundancy is desired in the future.

The C1000 container is suitable for outdoor installations and is of a rugged design engineered to protect the MicroTurbine equipment from the elements. Two basic container configurations are available to meet installation and environmental needs. The standard container is suitable for most outdoor installations while the high humidity model is suitable for any combination of higher wind loads, high humidity locations, marine applications, or areas that require higher seismic ratings. Refer to the Enclosure paragraph in Chapter 2: Product Overview for more details on the standard container options.

The individual 200 kW power modules share a common fuel header, control system and electrical output bus. The system is addressed from the single controller as one system, with a single aggregate power output rating. To the user, the package can be considered a single turbine generator set, with the advantages of higher efficiency over a wider operating range, higher availability and redundancy and the ability to upgrade to higher power outputs in the future.

MicroTurbine Engine (or Turbogenerator)

Each 200 kW power module within the C1000 series package is an integrated MicroTurbine generator that includes the combustion turbine (made up of a compressor, combustor, turbine, generator, and a recuperator) and the associated power electronics, control, and fuel system components required for power generation. The rotating components are mounted on a single shaft supported by patented air bearings and spin at a maximum speed of 60,000 RPM. The permanent magnet generator is cooled by the airflow into the MicroTurbine. The output of the generator is variable voltage, variable frequency AC. The generator is also used as a motor during start-up and cooldown cycles.

Fuel System

The MicroTurbine can efficiently use a wide range of approved hydrocarbon-based gaseous fuels, depending on the model. The C1000 Series MicroTurbine uses a single fuel header to power all installed power modules. A standard 4 inch 150# ANSI RF flanged gas inlet is available on the same end of the package as the controller and power connections. Each MicroTurbine power module includes an integral fuel delivery and control system. The standard system is designed for pressurized hydrocarbon-based gaseous fuels. Other models are available for low-pressure gaseous fuels, gaseous fuels with lower heat content, gaseous fuels with corrosive components, and biogas (landfill and digester gas) fuels. Contact your Capstone Authorized Service Provider for data on approved fuels and performance specifications.

Power Electronics

Digital power electronics control and condition the MicroTurbine electrical output. The digital power electronics change the variable frequency AC power from the generator to DC voltage, and then to constant frequency AC voltage.

During start-up, the digital power electronics operate as a variable frequency drive, and motor the generator until the MicroTurbine has reached ignition and power is available from the MicroTurbine. The digital power electronics again operate as a drive during cooldown to remove heat stored in the recuperator and within the MicroTurbine engine in order to protect the system components.

Electrical Output

Dual Mode C1000 Series MicroTurbines provide two electrical output connections: main power and auxiliary. The auxiliary power output is available before the main power is available and can be used for short periods of time to drive smaller three-phase AC loads from the optional battery system, such as an external fuel gas booster or heat recovery system water pump. Refer to Table 3-1 the electrical output ratings for the C1000 MicroTurbine.

Grid Connect units include only the main power connections and do not have auxiliary power connections. Note that the Auxilliary power is not in addition to the Main power output in Table 3-1.

Table 3-1. Electrical Output Ratings

	C600	C800	C1000
Main 3-phase AC power	600 KW	800 KW	1000 KW
Auxiliary 3-phase AC power (Dual Mode only)	30 kVA	40 kVA	50 kVA

C1000 Controller

The C1000 Series MicroTurbine includes an advanced user interface with a touch screen for control and monitoring of the C1000 components. This control system is typically located on the unit but can be placed in a nearby control room. The control system provides a simple, intuitive user interface and coordinates the operation of the digital system controls of each constituent power module. The C1000 controller is the turbine system's solitary controller and is the central hub for all user interface connections.

Options are available to communicate with the C1000 controller via RS-232 serial communications, Modbus, Ethernet modem, or internet. This includes remote monitoring by the customer or by Capstone service over the Capstone Service Network. Also, numerous industry standard protocols are available to facilitate full integration into any Building Management System, Supervisory Control and Data Acquisition (SCADA) or Programmable Logic Controller (PLC) based application.

C1000 Series MicroTurbine users have many controller configuration options to ensure power is dispatched according to their needs and with the highest possible efficiency and availability. Several methods are available for configuration through a controller connected laptop, the controller's front panel or via remote connection.

Exhaust

Capstone MicroTurbine technology provides high temperature, oxygen rich exhaust air so clean it can be used directly as a source of heat in some applications. When exhaust heat is utilized, overall system efficiency is increased. A properly designed MicroTurbine installation with waste heat recovery can easily exceed strict California Air Resource Board (CARB) standards for overall system efficiency. MicroTurbine waste heat is typically used with a heat exchanger or absorption chiller to heat or cool water to offset fuel and electricity costs without having any impact on the system electrical efficiency or generation capacity.

The exhaust from each 200 kW power module in the C1000 packages exits the module individually from the back where it can be directly vented to atmosphere or manifolded as required by a heat recovery application. With up to five individual exhaust streams, many options are available for optimizing the end user's heat recovery needs and several standard exhaust ducting kits are available for a number of possible configurations.

Control System Components

The C1000 unit controller is a supervisory control system with a full-featured Human Machine Interface (HMI), and remote control and monitoring capabilities. The controller addresses the C1000 as a single unit with a single power output rating, dispatching power demand automatically to the power modules in the most efficient and reliable way. This means that the operator addresses the C1000 as a single turbine generator, and not as separate power modules. Refer to Figure 3-3 for a block diagram of the C1000 Control System.

When the C1000 controller interfaces with the C1000 components, it is individually addressing the 200 kW power modules that make-up that C1000 package. Each of the 200 kW power modules has its own integrated control system for its turbine, generator and power electronics. This section describes in detail the architecture of the 200 kW power module controls that the unit level controller supervises.

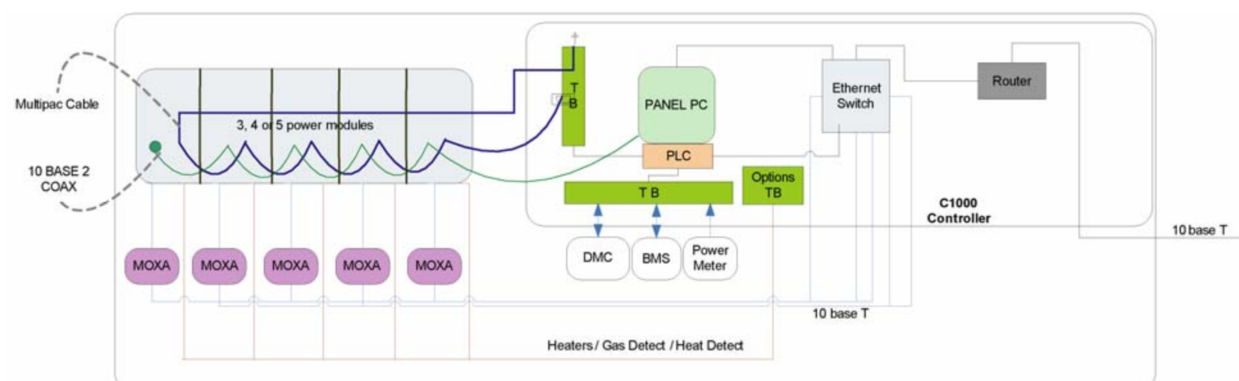


Figure 3-3. C1000 Control System Components

Each 200 kW power module in the C1000 MicroTurbine is controlled by its own digital system controller that works in unison with the controllers on the other modules to deliver the power output command issued by the C1000 unit controller. The power output command delivered to each power module is determined by the C1000 controller based on total power required, number of operating units, thermal priorities, engine run times and maximizing efficiency.

The system runs in one of two primary electrical operating modes. The first mode is called Grid Connect, where the system generates power at the level requested by the user and delivers it to the existing, active power grid in the user's facility. The other mode of operation is Stand Alone. In Stand Alone mode, the MicroTurbine is the sole source of electrical generation and generates the power necessary to support whatever load is connected to it as long as the load is below the maximum capacity of the generator.

Each power module in the C1000 Series MicroTurbine has its own primary independent digital controllers whose specific tasks are as follows:

- Load Controller, located in the Load Control Module
- Generator Controller, located in the Generator Control Module
- Engine Controller, located in the Fuel Metering Module
- Two identical Battery Controllers, one in each Battery Control Module
- System Controller, located in the System Control Module.

Connecting these controllers are a low voltage DC bus and a communication bus. Power and communication between the controllers flow over these bus connections as shown in Figure 3-4.

Each of the major components has an embedded Personality Module (PM). The PM is an Electrically Erasable Programmable Read Only Memory (EEPROM) device which is used to store operational parameters and user settings for each of these components. This allows the main operating software to identify, and adjust for the operation of, various machine configurations. The PMs can be read and programmed through the CRMS Software. Refer to the CRMS Technical Reference, Maintenance Edition (410014) for PM upload and download instructions.

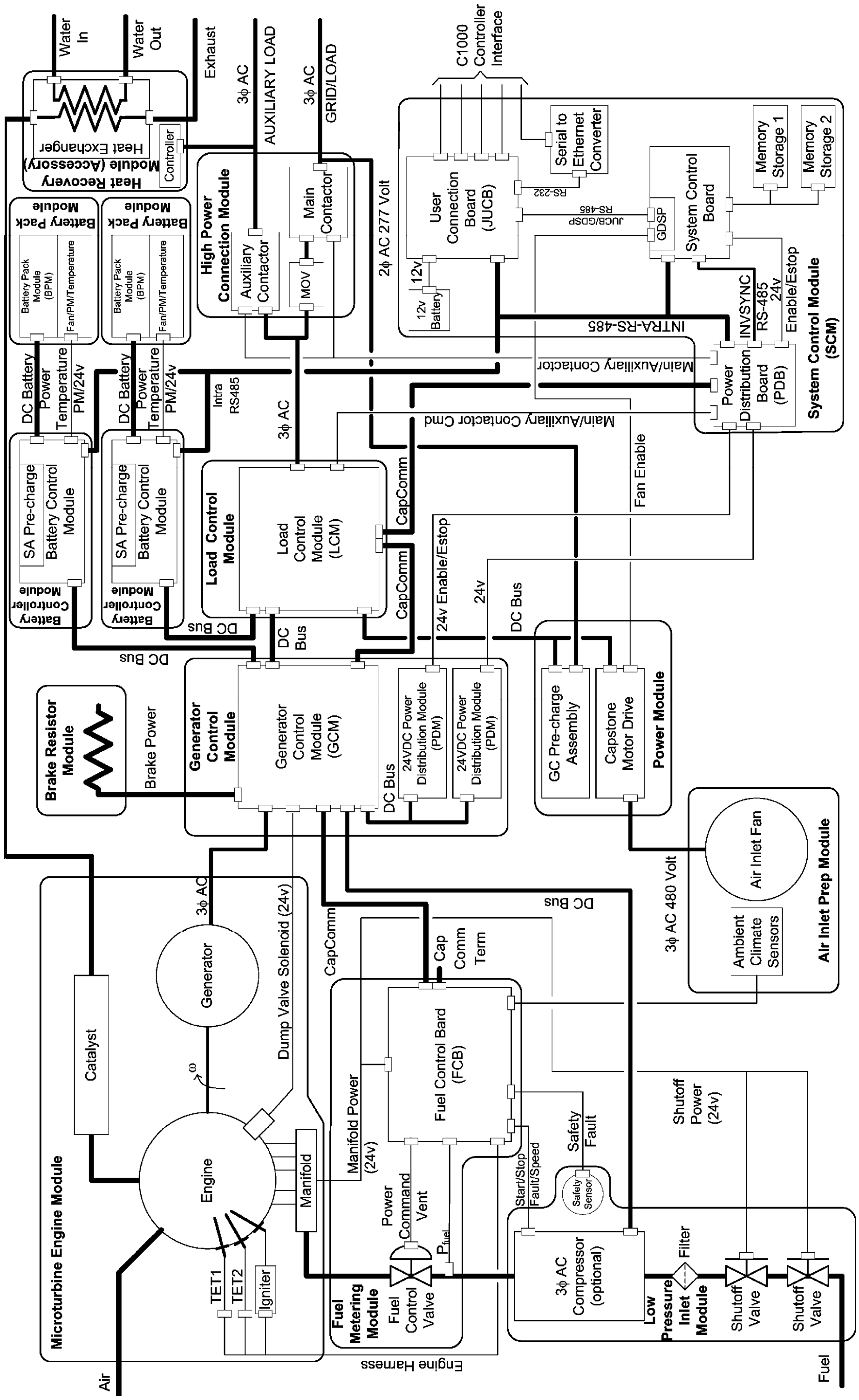


Figure 3-4. Major MicroTurbine Power Module System Components

Load Controller

The Load Controller on a 200 kW power module is one of the primary digital controllers. It is responsible for converting power from the high power DC bus to the customer's desired AC output voltage and frequency, or in the reverse direction to start the engine. In a Grid Connect system, the Load Controller automatically matches the existing voltage and frequency of the customer's grid.

Generator Controller

The Generator Controller on each 200 kW power module is dedicated to fully active speed control of the permanent magnet AC generator/motor. This controller provides high frequency AC power to initially accelerate the turbine/generator rotor to the required starting speed using power from the DC bus. Once the system lights off, the generator controller maintains the speed of the engine as required by output power demand. The Generator Controller converts the variable high frequency AC generator output to DC power for the high voltage DC bus. This controller also has control of the safety valve that opens and dumps compressed air overboard in the event of a loss of speed control, and a brake resistor that can be used to control excess power on the DC bus.

Fuel Controller

The Engine Controller on each 200 kW power module provides fuel control, ignition, engine temperature control, and monitors all engine sensors. The engine controller initiates the lighting sequence of the engine once the Generator Controller has accelerated the turbine generator rotor to the speed required for light-off. When ignition is detected, fuel flow is controlled to maintain an exhaust temperature set-point. The fuel control system independently controls each of the six injectors in order to maintain temperatures and is integral to the low emission and high efficiency of the MicroTurbine system.

Battery Controllers

Each 200 kW power module in Stand-Alone or Dual Mode configurations has two identical Battery Controllers that convert battery DC bus voltage from the two large DC batteries to system high power DC bus voltage. These controllers are responsible for the sourcing or sinking of power as necessary to regulate the DC bus. On Grid Connect configurations the inverter is used in place of the Battery Controllers to regulate DC bus voltage using grid power. During a start on a Stand Alone system, the Battery Controllers are responsible for turning on and charging the system's high power DC bus. Battery health and monitoring software resides in the Battery Controllers to manage the charge of the system's batteries and optimize battery life.

System Controller

The System Controller on a 200 kW power module is responsible for overall management of MicroTurbine operation and interfaces with the C1000 controller. The individual controllers described above are controlled, monitored and sequenced for complete system control. The system controller receives commands from the C1000 controller or can be serviced through Ethernet communications using CRMS software. The system controller logs all system faults and records data prior to, during, and after all logged faults for the last 20 faults on record. As an additional safety feature, it has control of all low voltage DC power to the fuel valves and will disable the fuel system, independent of the Engine Controller, in the event of a fault.

Operational States

Figure 3-5 and Figure 3-6 show the power module operational states and all possible transitions between states. The transitions and active states can differ between Grid Connect and Stand Alone operation. The fault logic will transition directly out of any state into the Disable, Warmdown, or Fault state depending upon the severity of the fault. If the user initiates a download of new software, then the system transitions to the Software Download state and remains there until the system is restarted to ensure that the power is cycled after downloading new software. This cycle of power is also required a system fault places the system in the Disable state.

Power Up

The Start-Up sequence differs for Grid Connect and Stand Alone modes:

- For Grid Connect, the turbine draws power from the grid connection, which is transmitted to the main electrical terminal connections on the C1000 package. Once grid power is applied, the system's DC bus precharge circuit powers up the main DC power bus that supplies power to the 24 VDC power supplies. These power supplies provide power throughout the system to all the individual digital controllers, placing the system in the Power Up control state.
- For Stand Alone or Dual Mode configurations, the user must first press the Battery Wakeup button located on the C1000 controller. This circuit supplies 24 V power from the C1000 controller back-up battery to the controller. The C1000 then initiates a power module Battery Wakeup by momentarily closing the power module external battery wakeup circuits. The external battery wake circuitry latches a contact that enables the precharge circuit on the battery controllers to activate the battery's main controller. The battery's main controller then energizes the system's primary DC bus using power from the main batteries.

While in the Power Up state, the System Controller goes through hardware and software system checks to verify that all power module subsystem controllers are operational. The power module system controller then determines if it is configured to be a Grid Connect, Stand Alone, or Dual Mode system. If there are errors during this process the system will transition to the Invalid state. If all Power Up checks pass, the system will transition to the Stand By state.

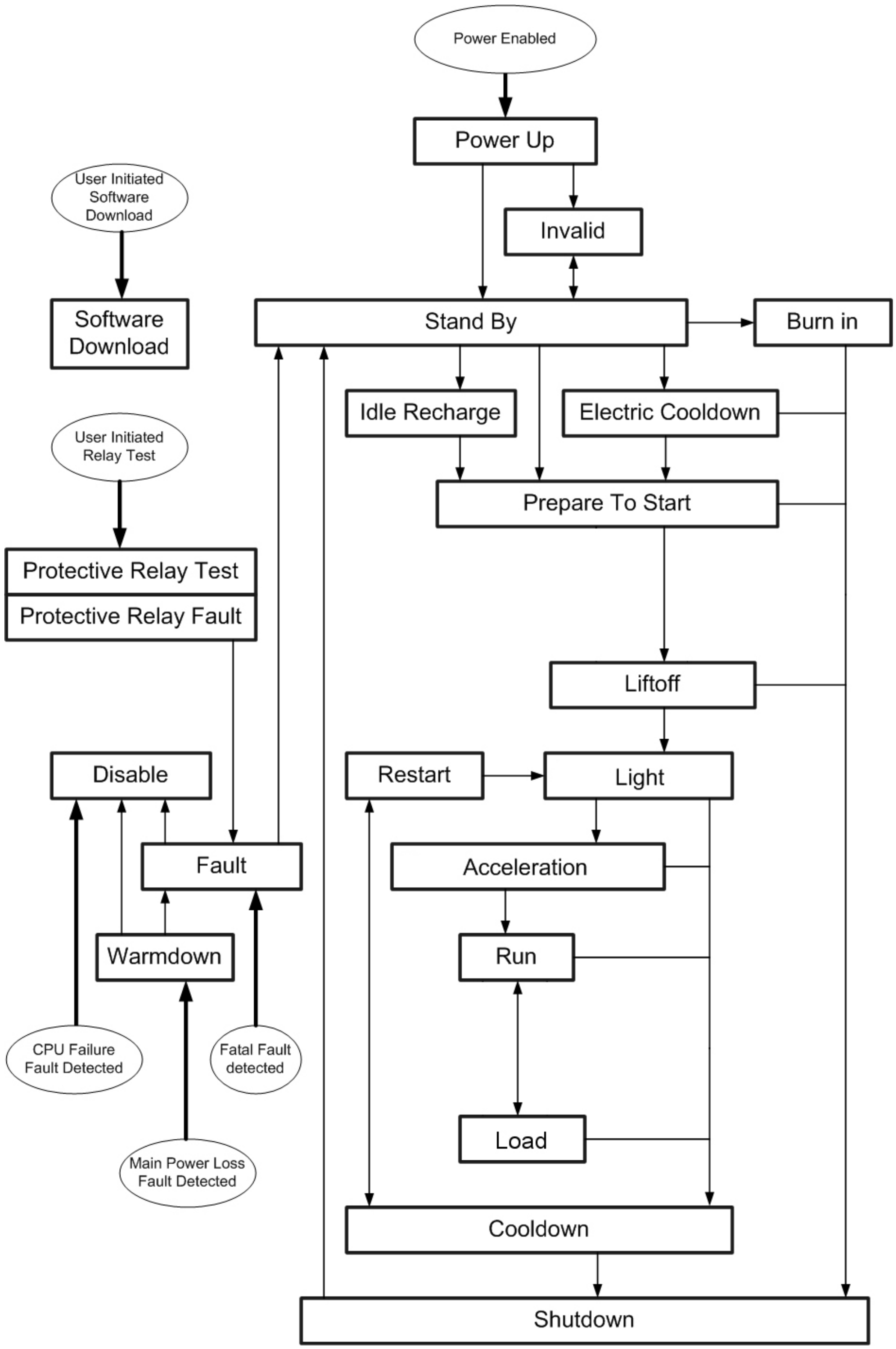


Figure 3-5. System Operational States – Grid Connect

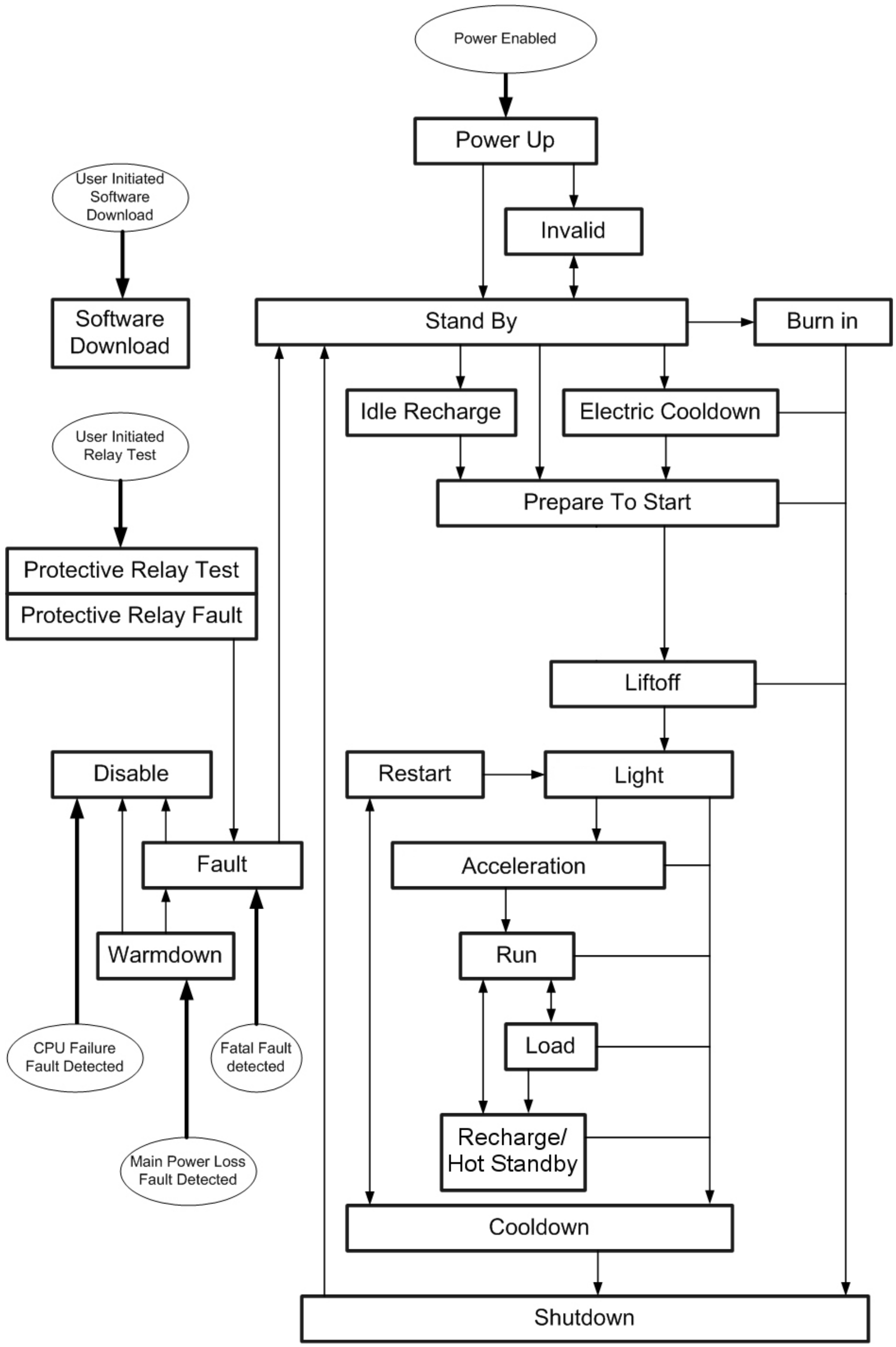


Figure 3-6. System Operational States – Stand Alone

Invalid

This is the system state transitioned to when the software or hardware does not match, or if there have not been any jumpers installed to identify the mode in which to run. New MicroTurbines are delivered with the operational mode unspecified and will be in the invalid state upon initialization.

Stand By

This is the primary state for the MicroTurbine after power up or anytime the unit is on but not issued a Start command. For Grid Connect, the system will stay in this state as long as grid power is applied to the terminals. For Stand Alone, the system has a timer that will turn off the power and wait for a battery wake-up command to start back up after the timer expires. This timer is user adjustable and prevents battery drain.

Burn In

This state is used to burn in new power electronics after initial installation.

Idle Recharge

This state is available for Dual Mode or Standby systems that have batteries but do not run in Stand Alone mode except in the very rare instances of a power outage. The user can command the system to this state to charge the main batteries. The MicroTurbine uses power from the grid to perform a complete charge of the batteries in order to maintain their health.

Cooldown

This state allows the Power Module fan to cool the power electronics if they are too hot for a system start.

Prepare to Start

This state prepares the system to run at power. It sets the proper operating modes and then enables the Load Controller, Generator Controller, and Battery Controllers (if present). Once these are functioning correctly, the primary cooling fan is powered.

Liftoff

The Generator Controller is commanded to bring the engine quickly up to its start speed using the reverse power to the generator. Once start speed is reached, the Generator Controller is put in speed control mode and the system transitions to the next state in the sequence.

Light

The System Controller commands the Engine Controller to initiate the light sequence. The Engine Controller fires the igniter and ramps the flow of fuel at the proper rate for the customer’s fuel type until ignition is detected. Once the system controller detects the lightoff, the System Controller places the Engine Controller in closed loop exhaust temperature control mode and transitions to the next state.

Acceleration

The system controller waits in this state until the Generator Controller has transitioned the engine speed up to the minimum engine idle speed before transitioning to the next state.

Run

The system stays in this state until the engine is fully warmed up and the load command is set by the user. Once both of these conditions are met, the System Controller transitions to the Load state.

Load

In this state, power is exported. In Grid Connect, the system will meet the commanded power export of the user. In Stand Alone mode, the system will maintain output voltage at whatever power is required up to the limit of the MicroTurbine output.

Recharge (Hot Standby)

This state is only active for Stand Alone systems. In Stand Alone, it is critical to make sure the batteries are charged prior to shutting down. Therefore, the System Controller disables the main output power, but continues to produce power with the engine, thus allowing the battery controllers to fully charge the main system batteries. The time for this charge will vary with the existing health of the batteries at the time of shutdown. Once the batteries are fully charged, the System Controller continues to the next state. The system is also available to transition back to Load state, such as when commanded to return to Grid Connect mode after a utility outage. This state is also referred to as Hot Standby.

Cooldown

In this state, the System Controller turns off the Engine Controller, which turns off the fuel to the engine. Once the fuel is off, the System Controller monitors the engine temperature until it has dropped enough to stop the engine. It then transitions to the next state.

Restart

This state exists to allow the user to restart the MicroTurbine without completely shutting down first. The System Controller commands the system back to the lightoff speed and then transitions back to the Open Loop Light state.

Shutdown

In this state, the System Controller commands the Generator Controller to run the engine back down to the Liftoff speed and then quickly to zero speed. Once the speed of the engine is confirmed to be at zero, the System Controller disables the Generator Controller, the Load Controller, and the Battery Controllers (if the system is in Stand Alone mode).

Software Download

This state ensures that the system is put in the proper configuration to load new software. The system automatically enters into this state upon starting a software upload through the CRMS software. Once the software load is complete, the user must cycle power in order to exit this state.

Protective Relay Test and Protective Relay Fault

This state allows a test of the protective relay functionality. If the proper fault is detected, the System Controller transitions to the Fault state.

Fault

This is the state that all active operating states (except the Standby state) transition to if a shutdown level fault is detected. Once everything is turned off, the system will clear the fault and transition back to Standby if the fault can be reset.

Warmdown

This is the state that all active operating states transition to if a fault occurs and disables the primary source of power after the engine has stopped providing power. In Grid Connect mode the primary source of power is the Load Controller while for Stand Alone mode it is the Battery Controllers.

Disable

This is the final state for all severe faults and can be transitioned to from any state. Once you enter this state, power in the entire system is shut down, and if in Stand Alone mode the system goes to sleep. If you are in Grid Connect mode and the precharge circuitry is still working, the controller and display could possibly stay on depending on the severity level and type of fault.

Power Electronics Components

Capstone C1000 MicroTurbine generator packages utilize advanced solid state high power electronics to provide high quality electrical power. In Grid Connect mode, the MicroTurbine supplies power as a current source to an energized electrical grid. In Stand Alone mode, the MicroTurbine supplies power as a grid-isolated voltage source.

Each 200 kW power module in the C1000 Series MicroTurbine has its own power electronics to rectify the high frequency AC generator output to high voltage DC and then to the desired voltage and frequency power output. Then each of the power module's output is bussed in parallel on the C1000 package's single power output. Figure 3-7 shows the C1000 electrical architecture for the main AC power output bus, and Figure 3-8 shows the C1000 electrical architecture for the auxiliary AC power output bus. Auxiliary AC power contacts are installed on C1000 Series MicroTurbines configured for Dual Mode operation, and are not available on C1000 packages configured to operate in Grid Connect only.

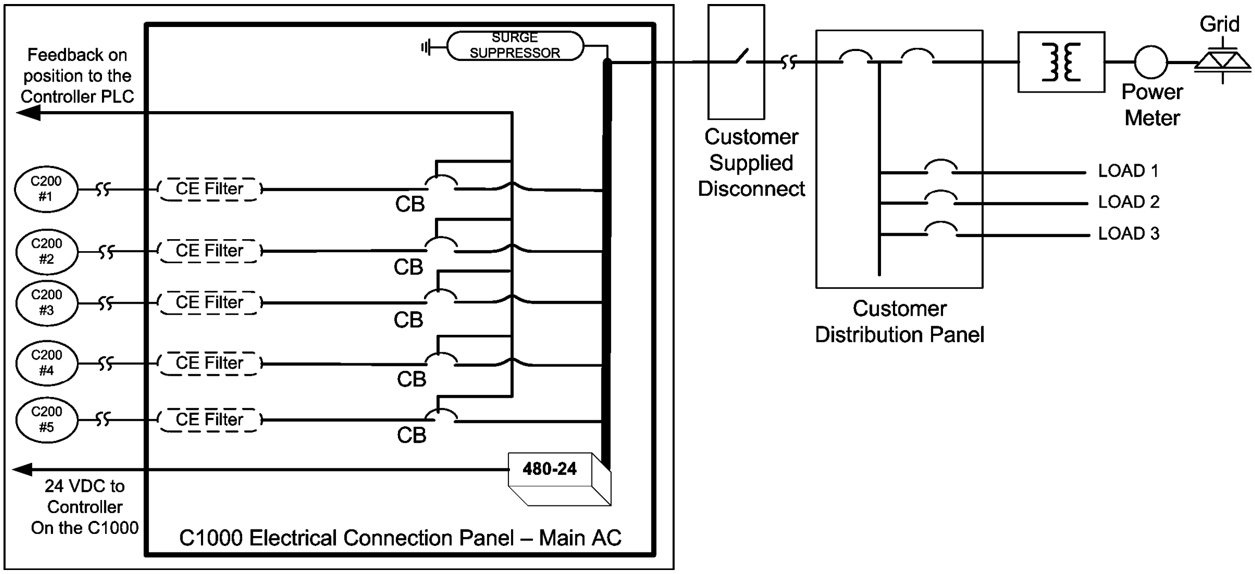


Figure 3-7. C1000 Electrical Architecture – Main AC

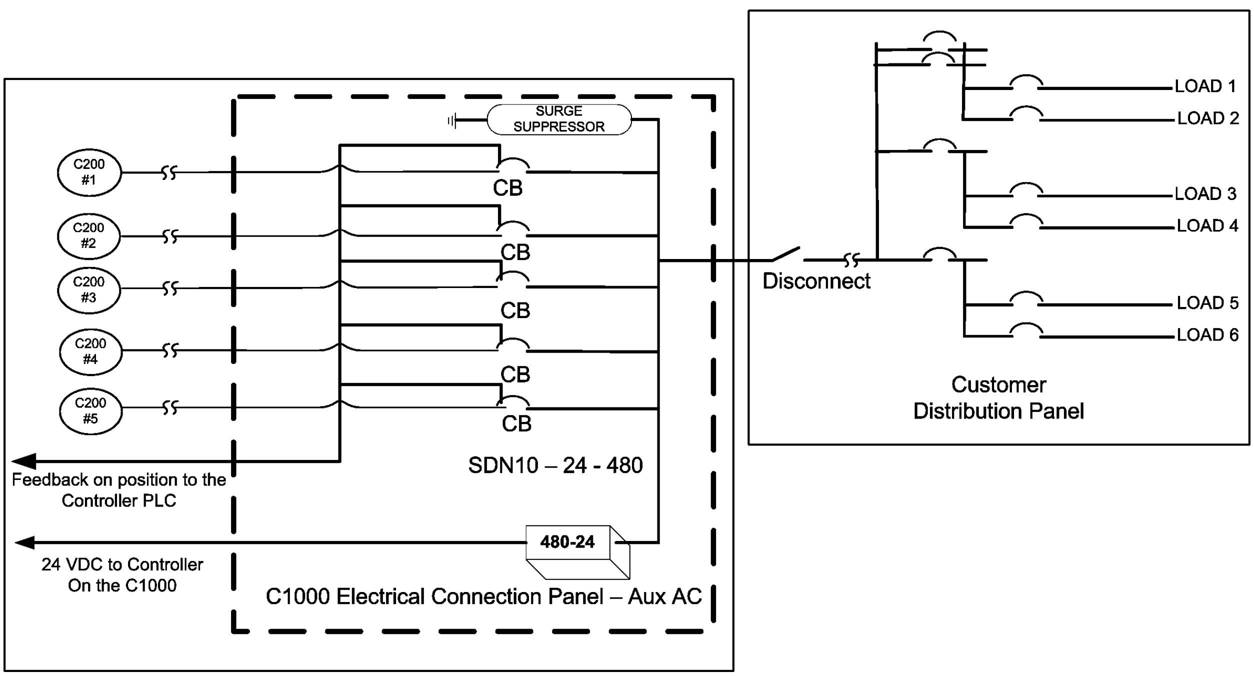


Figure 3-8. C1000 Electrical Architecture – Auxiliary AC (Dual Mode Only)

Figure 3-9 shows the major components and architecture of 200 kW power module's high power electronics. In the Control System Components section many of these elements were described from a controls perspective. Here they are discussed in regard to their role in producing output power.

- Generator Control Module
- Load Control Module
- Battery Control Modules (Stand Alone configuration only)
- Battery Packs (Stand Alone configuration only)
- Precharge Transformer
- Main Output Contactor
- Auxiliary Output Contactor
- Brake Resistors

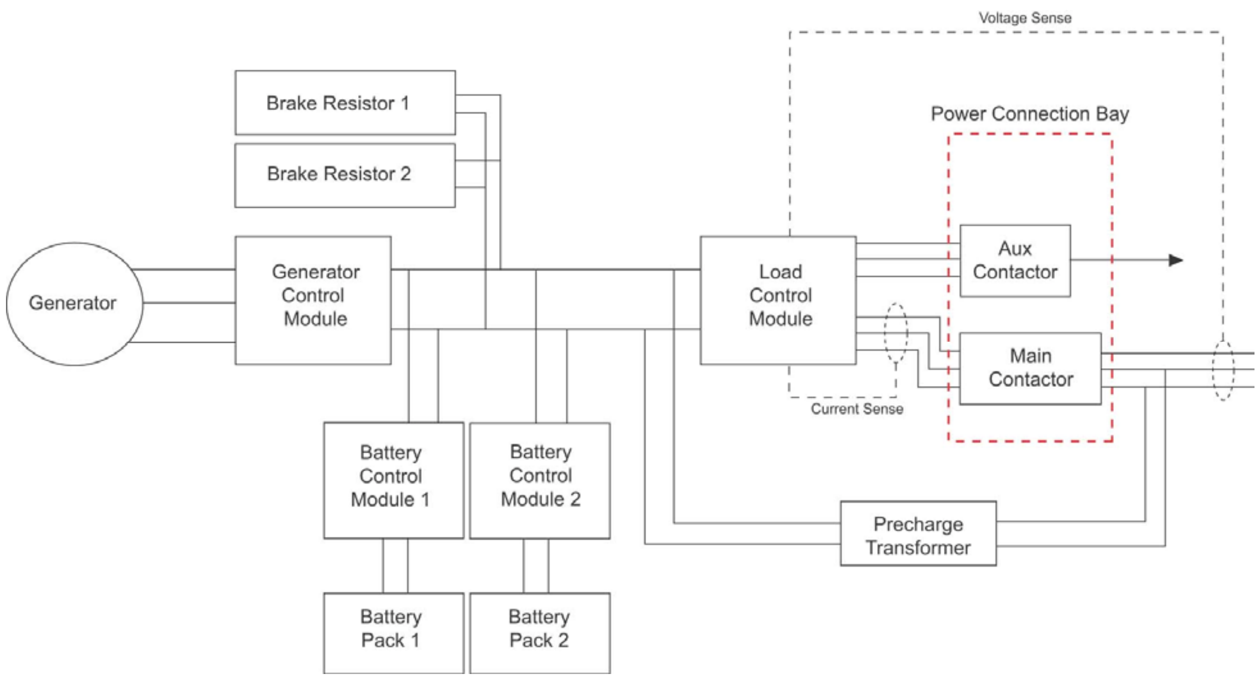


Figure 3-9. Power Module High Power Electronics Components

Generator Control Module

The generator control module converts the variable frequency, variable voltage output from the MicroTurbine generator into a high voltage DC bus.

Load Control Module

The load control module actively switches the output of the DC bus into synchronized 3-phase voltage and frequency.

Battery Control Modules

The battery control modules, included with Stand Alone or Dual Mode systems, convert the stabilized high DC voltage to a lower DC voltage as that of the battery packs.

Battery Packs

The Battery packs, included with Stand Alone (or Dual Mode) systems, provide the power electronics with stored energy for black starting and load transients.

Precharge Transformer

The precharge circuit serves in Grid Connect applications to activate the DC bus using grid power in order to initialize the power electronics. The precharge circuit limits the in-rush current to the DC bus during power up.

Main Output Contactor

The main output contactor is used to initiate and stop export of the system's main electrical power output, and is located in the Power Connection Bay.

Auxiliary Output Contactor – Dual Mode Only

An auxiliary output contactor provides a small amount of 3-phase AC power to selected loads before the main output contactor closes, and is located in the Power Connection Bay.

Brake Resistors

To prevent an overvoltage condition from occurring on the DC bus, a brake resistor is connected across to the DC bus. These resistors are activated when the DC bus exceeds a predetermined voltage setpoint which can occur as a result of rapid load shedding or an emergency stop.

CHAPTER 4: OPERATING MODES

This section describes the Grid Connect and Stand Alone operating modes, including transitions between these operating modes, MultiPac operation, and Dispatch modes.

Grid Connect

Introduction

Grid Connect mode allows the C1000 MicroTurbine package to be connected in parallel with an electric utility. When a utility grid disturbance occurs, the integrated protective relay functions of the 200 kW MicroTurbine power modules will automatically shut down the system. The C1000 package can restart automatically to resume supplying electricity to connected loads once grid power returns to normal. In Grid Connect mode, the C1000 MicroTurbine generator package is a current source only - the MicroTurbine synchronizes to the electric utility for both voltage and frequency reference. The MicroTurbine can be used to provide base load power or shave peak power based on loads or user commands.

Features

Grid Connect functionality and user benefits are optimized in the C1000 MicroTurbine package through several advanced features of the C1000 controller. Besides optimizing turbine efficiency for a given power output and minimizing emissions, the C1000 controller will balance power module run times and offers numerous custom and time of use controls for precise dispatch of power according to the user’s needs. The time of use feature includes programmable peak shaving functions, which automatically configure the MicroTurbine package to operate on a time schedule or to follow local loads during specific time periods, reducing peak demand charges. These special features are described as Time of Use and Load Following dispatch modes later in this chapter. Time of Use supplies variable power levels at selected times to meet user load demand. Load Following tracks local electrical loads to supply power on an as-needed basis.

The C1000 controller also includes Modbus, discrete, and Ethernet interfaces to external systems, such as utility power meters, rate meters or Building Management Systems. These interfaces can provide even better optimization of your electrical generation and heat recovery needs, providing optimized operational modes based on electric demand, heat demand and utility pricing. Reverse Power Flow Protection is easily included and prevents the MicroTurbine system from backfeeding power to the grid. Implementation of Load Following mode and Reverse Power Flow Protection requires installation of an external power meter and/or a timer or switch. The external power meter provides information to the MicroTurbine on power flow at a point between the MicroTurbine and the grid power supply.

Power Specifications

The full-load power output in Grid Connect mode is three phase 400 to 480 V, 50/60 Hz. The MicroTurbine automatically synchronizes with the grid, and will operate properly with either clockwise or counter clockwise phase rotation. For complete performance ratings, refer to Chapter 7: Performance and Chapter 8: Electrical Ratings in this document. For discussion of the protective relay functionality, refer to Chapter 9: Protective Relay Functions. For discussion of electrical interconnections, refer to Chapter 8: Electrical Ratings and Chapter 12: Installation in this document.

Configuring Grid Connect Mode

The C1000 MicroTurbine package must be configured for grid connect mode through hardwire connections in the User Connection Bay, and through software commands from the control panel or through the serial communications ports using a PC with CRMS-APS. To operate in Grid Connect mode, the following needs to be done:

- Set the System Power Connect mode to Grid Connect using the control panel or using a PC with CRMS-APS.
- Provide external control connections to the Grid Connect enable input in the C1000 Controller. Refer to Dual Mode below for a discussion of how to switch between Grid Connect and Stand Alone modes. Refer to Chapter 10: Communications in this document for details on pin connections.

In addition to this Grid Connect mode setup, the means to start and stop the system must be configured. The sections below provide additional functions to be considered for setting up dispatch modes. The Chapter 10: Communications provides description of other input and output options, including Emergency Stop and fault inputs.

The system power demand will also need to be set. Refer to the C1000 User's Manual (400024) and CRMS-APS Technical Reference User Edition (410074) for configuring all these settings.

Auto Restart

By means of the Auto Restart feature a MicroTurbine system automatically attempts a restart after low-severity incident-driven shutdowns. If Auto Restart is on, the system will attempt to restart after a shutdown due to any fault condition that is severity level 3 or less. This feature may be enabled with any of the dispatch modes described below. Capstone recommends enabling Auto Restart to increase system availability, deliver faster power output and reduce wear on the bearings.

Note that setting Auto Restart to ENABLE impacts both Grid Connect and Stand Alone operating modes. Separate adjustable timers can be used to set different restart time delays for Grid Connect and Stand Alone modes. These timers are only adjustable using CRMS.

If the Auto Restart feature is enabled, the system stores the ON command through a loss of utility power. However, the MicroTurbine must be explicitly commanded ON for the Auto Restart operation to function. For example, the system will not automatically restart and reconnect to the grid if the Time of Use mode is not telling the system to be ON at that point. Operator intervention is required to manually restart the system if a utility fault condition occurs and the related protective relay function shuts the MicroTurbine down.

The Auto Restart feature is available in both the Grid Connect and Stand Alone operating modes. However, each mode has a separate user-settable delay timer that is adjustable between zero and 60 minutes.

Grid Connect Operation

Once the system has been properly wired to the utility grid and any external control wiring has been established, a Capstone Authorized Service Provider is required to complete the commissioning procedure and set protective relay settings. The end user can then refer to the C1000 User's Manual (400024) for proper operation and maintenance of the system.

Stand Alone

Introduction

This section presents information on operating the C1000 MicroTurbine package in Stand Alone mode. Stand Alone mode allows power generation at locations where there is either no electric utility service or where backup power is desired when the electric utility is unavailable. For Stand Alone operation, the voltage and frequency of the MicroTurbine system are set to meet load requirements. The MicroTurbine behaves as a voltage source that always follows the power requirements of the load, (i.e., the output power is determined by the actual current draw demanded by the connected loads).

The MicroTurbine package in Stand Alone mode utilizes an on-board battery storage system to power connected loads when no electric grid utility is available. The batteries provide energy for starting the MicroTurbines. During operation, the batteries also provide energy for supporting transient load changes while the MicroTurbines increase speed to provide the power required by the load. In addition, it serves as a buffer to absorb energy during a loss of load while the MicroTurbine decelerates to produce less power. During MicroTurbine shutdown, the battery may be placed in sleep mode to minimize drain and preserve battery charge. Management of the battery and its state-of-charge is automatic during MicroTurbine operation.

Features

Most Stand Alone installations require the connected loads to be brought on-line once the MicroTurbine load controller is producing the required voltage and frequency. Stand Alone systems can also be configured for a Soft Start function, which allows the MicroTurbine to begin exporting power at less than nominal voltage and frequency, and then linearly increases voltage and frequency to nominal levels over a period of time. This Soft Start feature can assist in starting loads with large in-rush currents, such as a single large dedicated motor. To meet output power requirements automatically, the system can be configured in Auto Load mode. Auto Load ensures that the MicroTurbine closes the main output contactor to immediately produce the required output power once minimum engine load speed and battery state of charge are reached.

The C1000 MicroTurbine package includes integrated protective relay functions to check output voltage and frequency, and will shut down if values fall outside of preset limits. The system will also automatically shut down, and will not pick up load, if it senses utility voltage. If the connected loads demand more power than the engine is able to produce, the MicroTurbine will take additional power from its battery storage system to make up the difference until the battery state of charge drops below 60 percent.

Power Specifications

The full-load power output in Stand Alone mode is three phase 150 to 480 V, 50/60 Hz. The MicroTurbine provides output in L1, L2, L3 counterclockwise phase rotation. For complete performance ratings, refer to Chapter 7: Performance and Chapter 8: Electrical Ratings. For discussion of the protective relay functionality, refer to Chapter 9: Protective Relay Functions. For discussion of electrical interconnections, refer to Chapter 12: Installation.

Configuring Stand Alone Mode

The C1000 MicroTurbine package must configured for Stand Alone operation through hard-wired connections in the User Connection Bay, and software commands from the C1000 controller or through the C1000 controller using a PC with CRMS. To operate in Stand Alone mode, the following needs to be done:

- Set the System “Power Connect” mode to “Stand Alone” using the C1000 controller or a PC with CRMS.
- Provide external control connections to the Stand Alone enable input in the User Connection Bay. Refer to Dual Mode below for a discussion of how to switch between Grid Connect and Stand Alone modes. Refer to Chapter 10: Communications for details on pin connections.

In addition to this Stand Alone mode setup, a means to start and stop the system must be configured. The sections below provide additional functions to be considered for setting up soft start and dispatch modes. The Communications chapter provides description of other input and output options, including Emergency Stop and fault inputs.

The system voltage and frequency will also need to be set. Refer to the C1000 User’s Manual (400024) and CRMS-APS Technical Reference User Edition (410074) for configuring all these settings.

Auto Load

The Auto Load option allows the user to enable the MicroTurbine to automatically close the output contactor once the system has started and is ready to load. A “Yes” setting automatically makes power available to match the load demand. A “No” setting requires the user, through the C1000 controller, to manually enable the MicroTurbine to produce power to meet the load demand. This command can also be set through the serial port using CRMS. The Auto Load feature should be enabled to have the contactor automatically close when Auto Restart is enabled and a restart fault occurs.

Stand Alone Load Wait

The Stand Alone Load Wait function applies only to Dual Mode configured systems. This provides a timer that maintains the system in Stand Alone Load State before the transition back to Grid Connect, after the utility grid has returned to normal. The timer begins when the utility voltage and frequency are detected to be within the required operating range, and maintains the turbine in the Stand Alone load state until the time has expired. This timer is adjustable from 5 to 30 minutes.

Soft Start Functionality

In most applications, the C1000 package provides the user-defined voltage and frequency as soon as the main output contactor is closed. The C1000 MicroTurbine package may also be configured to begin exporting power at less than nominal voltage and frequency, and then linearly ramp to nominal values over a selected time period using the Soft Start functionality. Both voltage and frequency can be adjusted for this initial soft start function using CRMS software. This functionality impacts all connected loads and is most likely only useful in application where the single driven load is a large electric motor.

Soft Start Voltage

The Soft Start Voltage (0 to 480 V) setting is typically used to enable the MicroTurbine to start a motor (or other loads), which cannot handle full load current immediately. This parameter differs from the Operating Voltage setting (150 to 480 V), which represents the load voltage at normal operating conditions. When the output contactor closes, the system will provide demanded current at this starting voltage and immediately begin increasing the voltage at the configured rate, up to the nominal voltage. The Start voltage can be adjusted from 0 to the normal voltage setting. Ramp Rate Volts per Second establishes the rate of voltage increase. When the output contactor closes, the system will provide demanded current at the voltage established above and immediately begin increasing the voltage at this rate. The Ramp rate can be set from 0 to 6,000 Vrms per second

Soft Start Frequency

Soft Start Frequency establishes the starting frequency. When the main output contactor closes, the system will provide demanded current at this starting frequency and immediately begin increasing the frequency up to the nominal frequency. The Start frequency can be adjusted from 0 to the normal frequency setting. Ramp Rate Hertz per Second establishes the rate of frequency increase. When the output contactor closes, the system will provide demanded current at the starting frequency and immediately begin increasing the output frequency at this rate. The Ramp rate can be set from 0 to 2,000 Hz per second.

Battery Overview

Each Stand Alone 200 kW power module contains two sets of batteries: the main batteries (made up of two banks or sealed lead acid batteries) that provide power for starting the engine and to stabilize power output during load transients, and a small 12 VDC battery in the User Connection Bay (UCB) to provide energy to wake-up and engage the main battery system is engaged. Additional details on the main battery system are included in Chapter 5: Battery Management.

The C1000 controller, on a C1000 Series MicroTurbine configured for Dual Mode, also has an Uninterruptible Power Supply (UPS) battery for Stand Alone operation.

Main Battery Isolation Switch

A battery isolation switch located within the 200 kW power module can be used to disable the MicroTurbine for service or transport. The switches on the two main battery packs in each 200 kW unit must be set to ON for system operation. Refer to the C1000 User's Manual (400024) for details.

UCB Battery

Each 200 kW power module uses a separate battery located in the Communications Bay for remote system battery wake-up functionality. The +12 VDC battery is recharged automatically when the MicroTurbine senses a low state-of-charge.

C1000 Controller Battery

In a Dual Mode system, the C1000 controller includes a UPS battery. During Stand Alone operation, the C1000 controller receives power from the auxiliary AC power bus. However, the UPS is needed to power the C1000 controller in Stand Alone until the MicroTurbine package is started and the auxiliary contactor is closed. In a Grid Connect only system, C1000 controller power comes from the grid.

The 24 VDC power from the UPS is connected to terminal block TB2, pins 1 and 21, of the C1000 controller for distribution to the components in the controller. Input voltage, converted to 24 VDC from auxiliary 480 VAC, is routed to the UPS from terminal block TB1, pins 1 and 2. When the UPS senses zero volts at pins 1 and 2 of TB1, the backup battery in the UPS supplies 24 VDC to TB2, pins 1 and 21. Refer to Appendix B: C1000 Controller Schematic.

The controller UPS battery is sized to enable a controller boot and sufficient run time to start the connected MicroTurbines, at which time the controller back-up battery recharges. In extended power outages, a 24 volt source may be needed to power the C1000 controller for an initial start. More details are included in Chapter 5: Battery Management.

System Sleep Mode

Models in the C1000 MicroTurbine series include a Sleep Mode to conserve battery power during prolonged periods of inactivity. This reduction in battery draw can significantly extend the life of the MicroTurbine power module battery charge and the UPS battery in the C1000 controller. Sleep Mode inactivity time can be adjusted from 0.1 to 23.9 hours.

NOTE	If the battery isolation switch is set to ON, and the display panel is dark, the system is most likely in Sleep Mode.

Stand Alone Operation

Once the system has been properly wired to its loads, and any external control wiring has been established, a Capstone Authorized Service Provider is required to complete the commissioning procedure and set protective relay settings. The end user can then refer to the C1000 User's Manual (400024) for proper operation and maintenance of the system.

Dual Mode

Capstone uses the term Dual Mode to describe the ability to automatically switch between Grid Connect and Stand Alone operating modes. By definition, a Dual Mode MicroTurbine system includes the batteries and associated hardware to be able to operate in Stand Alone mode. Sometimes a Dual Mode version is used for a purely Stand Alone application (for example, remote power that will never be connected to a utility grid). In this case, the Dual Mode features described here will not be used, and only the Stand Alone operation description above will apply. For many applications, however, the system is intended to operate in Grid Connect mode most of the time and transition to a Stand Alone mode when the utility grid experiences a fault.

Configuring Dual Mode Operation

As described in the Grid Connect and Stand Alone sections above, the MicroTurbine package must be configured for the correct mode operation. This requires both hard-wired connections in the User Connection Bays on the individual power modules and software commands from the C1000 controller or from a PC with CRMS-APS. To operate in Dual Mode, the following needs to be done:

- Set the System Power Connect mode to Dual Mode using the C1000 controller and a PC with CRMS-APS.
- Provide external control connections to the Stand Alone enable and Grid Connect enable inputs in the User Connection Bay of each 200 kW power module. Refer to Chapter 10: Communications in this document for details on pin connections.

Once the system is configured to act in Dual Mode, the C1000 controller can activate the Stand Alone or Grid Connect inputs on each MicroTurbine power module to automatically switch between Grid Connect and Stand Alone operating modes. Care needs to be taken to avoid conflicting commands that could damage equipment. Capstone offers a Dual Mode System Controller (DMSC) accessory that provides the necessary wiring and logic to sense utility grid problems and automatically switch between these two operating modes. The DMSC (or third-party accessory equivalent in function and rating) is required equipment for Dual Mode operation. Without it, the C1000 controller cannot operate the external breakers needed to disconnect from and reconnect to the grid. The DMSC also provides Fast Transfer switching as described in the Fast Transfer paragraph below. Refer to the DMSC Technical Reference (410071) and to the DMSC User's Manual (400023) for the description and operation of the DMSC.

CAUTION	The MicroTurbine can only provide power in L1, L2, L3 counterclockwise phase rotation in Stand Alone mode. Therefore, proper phase wiring must be respected relative to the utility grid voltage. Connections L2 and L3 to the MicroTurbine may need to be swapped to achieve a consistent phase rotation when switching between utility voltage in Grid Connect mode and MicroTurbine voltage in Stand Alone mode to avoid damage to loads that are sensitive to phase rotation.

Fast Transfer

The C1000 MicroTurbine packages are able to transition from Grid Connect to Stand Alone mode in less than 10 seconds. The MicroTurbine is not able to reconnect to a utility grid without first sensing grid voltage stability for at least 5 minutes (refer to Grid Connect above). However, protected loads can be quickly transitioned back to a utility source by first stopping MicroTurbine power output in Stand Alone mode, and then reconnecting the protected loads back to the utility. The MicroTurbine can then continue to operate in a Hot Standby mode (producing no load power but recharging its batteries) until it senses the utility is stable and then reconnecting automatically in Grid Connect mode.

The Dual Mode System Controller Technical Reference (410071) provides details about the transitions and timing for fast transfer.

MultiPac

This section provides technical information for operating the Capstone C1000 MicroTurbine package in a collective arrangement known as a MultiPac. The C1000 package requires the use of the Capstone Advanced Power Server (APS) for MultiPac applications. The APS allows up to 20 C65 and C200 units, and 10 C1000 units (any combination of C600, C800 and C1000) to be operated as a single power generation source. All of the logical groupings and dispatch modes for the MultiPac are available from the APS. Refer to the Capstone Advanced Power Server Technical Reference (480023) for details utilizing an APS in MultiPac installations.

MultiPac operation features synchronous voltage and frequency for all MicroTurbines in the group. Individual MicroTurbines share power and load on both a dynamic and steady state basis. A single physical and logical control point designated as the Master directs signal and command information to all other turbines. The APS must be designated as the Master.

A MultiPac can be operated in either of the operating modes described above: Stand Alone or Grid Connect. In each mode, individual MicroTurbines share power, current and load on both a dynamic and steady state basis, and generate current to meet the required load demand. Dual Mode operation requires purchase of a Capstone Dual Mode System Controller.

An illustrative interconnection diagram is presented in Figure 4-1.

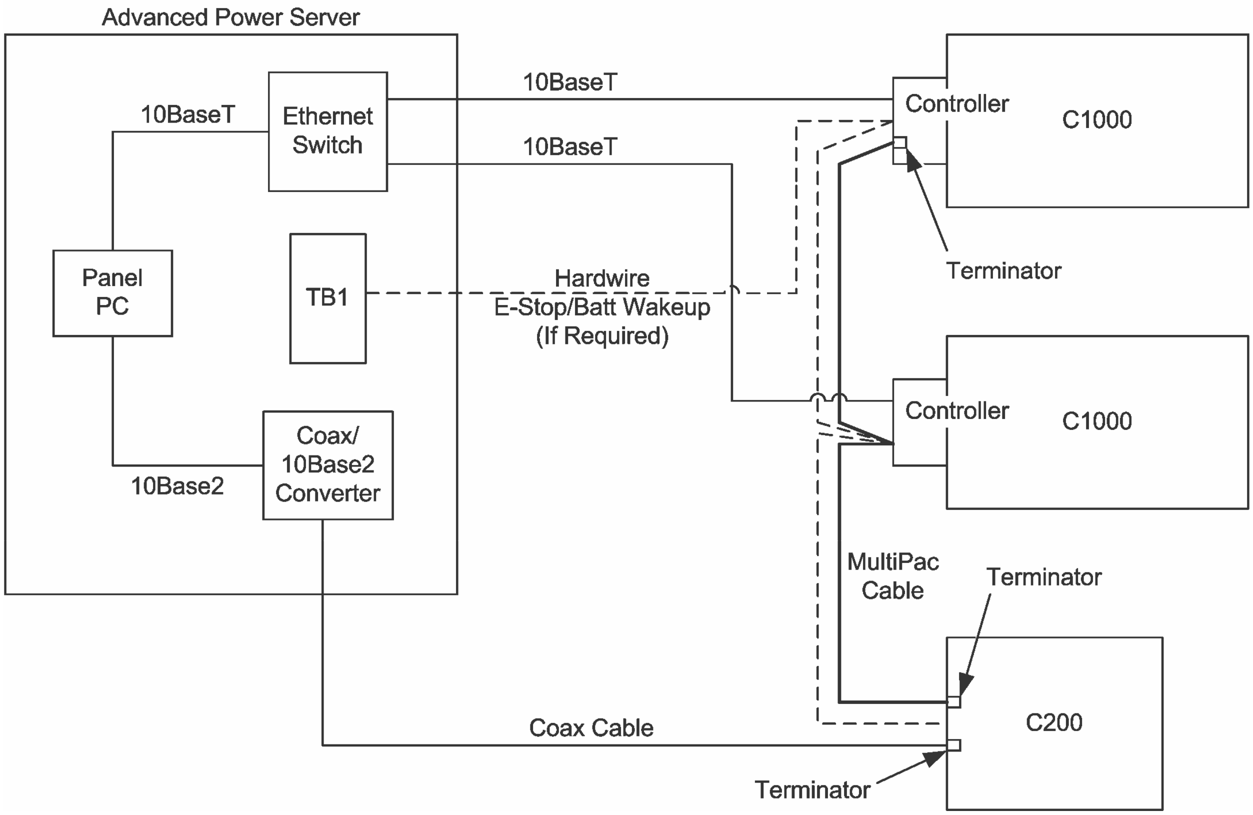


Figure 4-1. Typical MultiPac Interconnection with C1000 Packages

MultiPac Communications

Capstone MicroTurbines use two digital communications connections between systems in a MultiPac to allow information to be shared:

- Load Control – Ethernet is used for command and control. Commands (i.e. start/stop, power demand) are input to the APS which acts as the MultiPac master. The APS then sends resulting commands to each MicroTurbine in the MultiPac. The APS routinely queries all MicroTurbines connected to it for operational and fault data. Users can request data from any turbine through the APS.
- Inverter Synchronization – in Stand Alone mode, one turbine serves as an Inverter Master, passing voltage and frequency signals to all other turbines for synchronization using RS-485 signals. Note that the Inverter Master does not have to be the MultiPac Master, and requires no additional configuration other than setting up the MultiPac through the APS. The MultiPac cable includes the RS-485 communications and also includes global E-stop and Battery Wake-up lines so that these hardwired commands can be immediately passed from the APS to all other MicroTurbines in the MultiPac. The APS will wake the entire MultiPac. The C1000 controller of a C1000 Series MicroTurbine in a MultiPac will only wake the local modules in the C1000 package.

Refer to Chapter 10: Communications in this document for details on these digital communications connections.

Configuring MultiPac Operation

MultiPac operation with the C1000 packages requires the use of the Advanced Power Server (APS) as Master for the MultiPac of C65, C200 and C1000 packages. The MicroTurbines that are included in the MultiPac must have a common inverter synchronization signal and must each be connected to the APS via Ethernet. This may require the installation of a co-axial to Ethernet converter at each MicroTurbine package. MultiPac must be enabled on each constituent MicroTurbine in the MultiPac through the unit's controller display (if not a C1000) or through a PC running CRMS.

The APS must be configured with operational modes, dispatch modes and functional groupings of connected MicroTurbine equipment as required by the application. More detail on configuration of the APS can be found in the Advanced Power Server User's Manual (400011).

MultiPac Operation

MultiPac operation is designed to maximize the combined output power of multiple MicroTurbines. It also offers redundancy - if an individual turbine shuts down due to a fault (depending on the fault), remaining units will still continue to function. Additional functionality is available in MultiPac installations using the APS (which is always required when C1000 packages are in a MultiPac):

1. Automated control of up to 10 C1000 MicroTurbine packages and 20 C65 or C200 MicroTurbines; schedule start and stop times based on time of day, power required, utility pricing or more complex logic.
2. Optimize the value of your MicroTurbine installation; run your units based on power demands, economic benefit, waste heat utilization or emergency backup power requirements.
3. Maximize the efficiency and minimize the emissions of multi-unit installations; Max efficiency mode allows the highest electrical efficiency to be reached across a much broader output range through intelligent allocation of power demand to individual MicroTurbines.
4. Reduce maintenance costs with Run Time Balance; the APS ensures that MicroTurbines accrue operating hours equally, aligning scheduled maintenance.
5. Control and monitor all your MicroTurbines from one full featured, touch-screen HMI. System integration through Modbus or hardwire is available from a supervisory controller or Building Management System.
6. Remote, continuous and secure monitoring by the Capstone Service Network (CSN) is available to maximize uptime, better schedule service and track historical performance data.

Please refer to the Advanced Power Server User's Manual (400011) for complete information on system abilities, configuration and system requirements.

Load Management Modes

Load Management Modes allow the C1000 controller to provide a fixed or variable output power as required by the installation in order to optimize the benefit of the MicroTurbine installation while operating in Grid Connect mode. The functional load management mode will determine the required output power for the C1000 package. Load management does not apply to Stand Alone operation, since the output power is determined by the connected loads. The three Load Management modes available are Normal (or Base Load), Time of Use, and Load Following. Refer to the CRMS-APS Technical Reference User Edition (410074) for how to select and configure these Load Management modes. Base Load power set point can be selected directly through the C1000 controller display while Time of Use and Load Following modes must be configured through CRMS-APS.

Normal (Base Load)

Normal operating mode is the initial factory setting for Grid Connect operation. When operating in Grid Connect mode, the Normal Dispatch mode generates power according to the stored Demand setting. The electric utility grid provides the remaining power to meet the total customer load. This dispatch mode is also referred to as "Base Load" mode. Figure 4-2 illustrates a C1000 MicroTurbine package operating Grid Connect in this Base Load (Normal) mode. In the example, the MicroTurbine supplies 200 kW base power and the electric utility grid supplies the rest of the load demand.

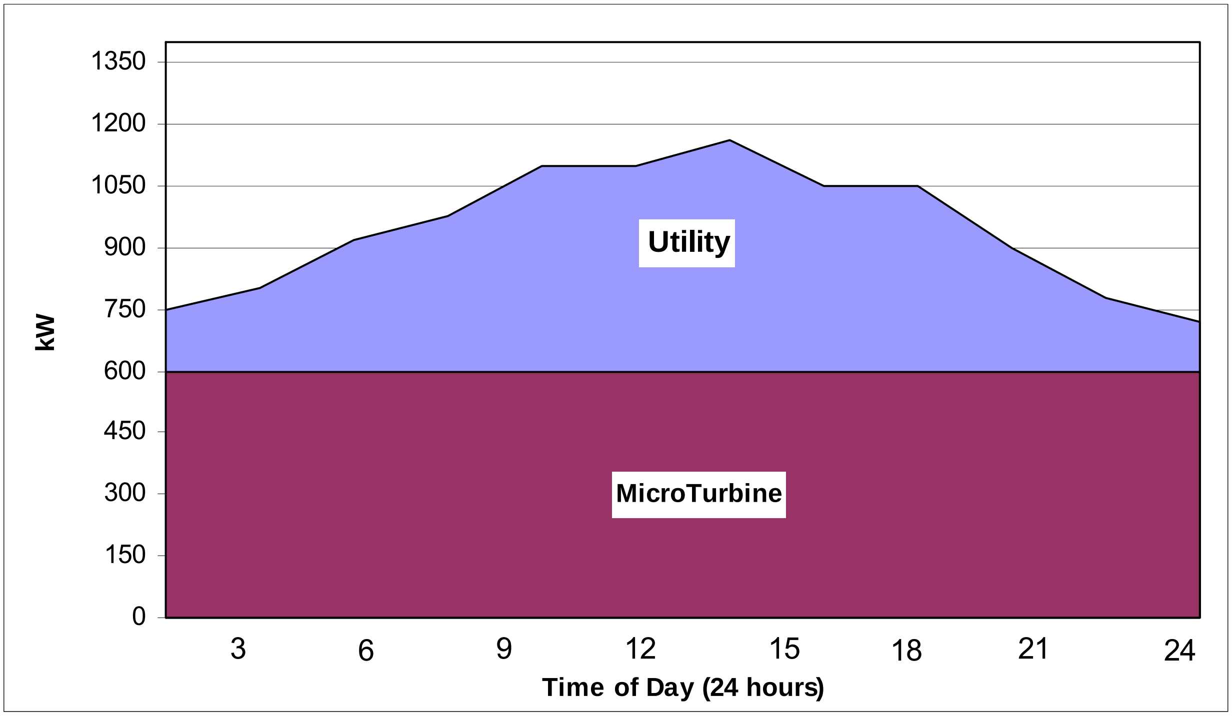


Figure 4-2. Grid Connect Operation in Normal (Base Load) Dispatch Mode

Time of Use

The Time of Use dispatch mode may be used for peak shaving during periods of the day when electricity from the utility is at a premium. Time of Use mode allows the user to selectively determine start/stop commands and/or power output levels for up to 20 timed events. Events are programmed by day of week, time of day, and power demand in any order, and sorted by time to determine event order. Figure 4-3 illustrates how a C1000 MicroTurbine package operating in Grid Connect may be used in Time of Use mode.

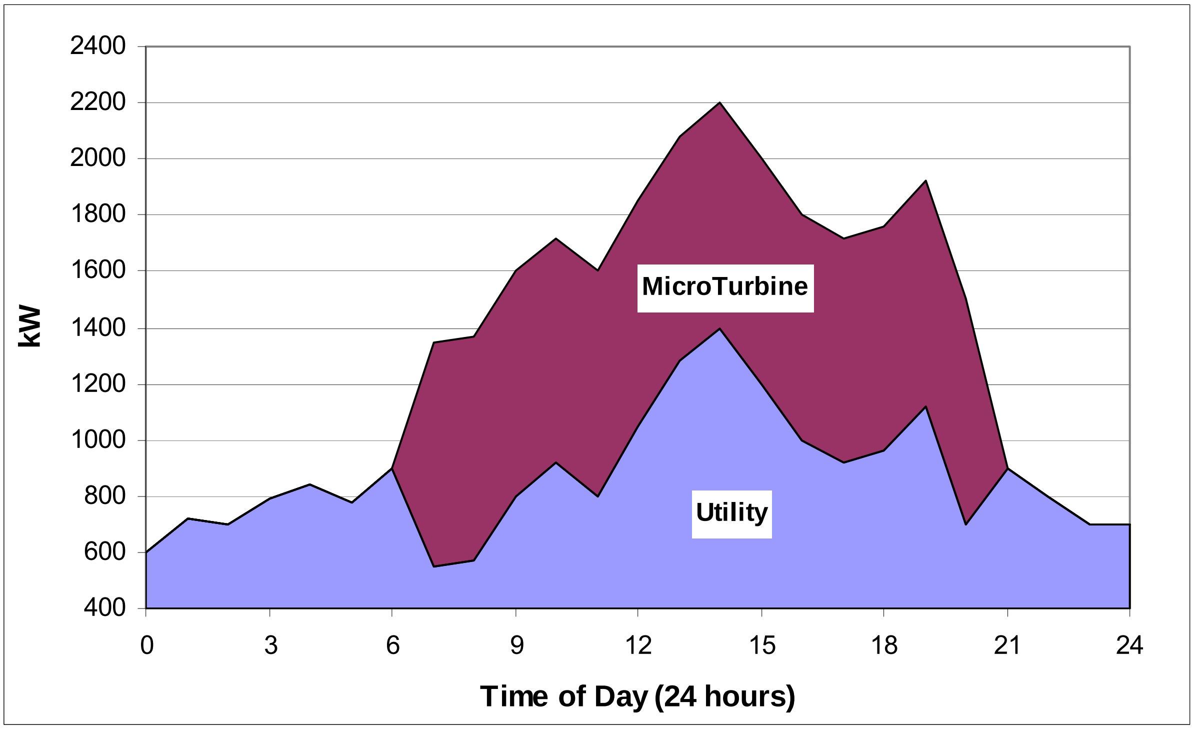


Figure 4-3. Grid Connect Operation in Time of Use Dispatch Mode

Time of Use is configured using a PC with CRMS-APS software. Refer to the CRMS-APS Technical Reference User Edition (410074) for configuring this dispatch mode. The dispatch mode is set for the C1000 unit through CRMS-APS, the C1000 controller determines how the constituent power modules deliver the required power.

Load Following

NOTE	Load Following requires an external power meter. The power meter is not supplied with the MicroTurbine and must be connected between the MicroTurbine and the electric service entrance. Refer to Chapter 10: Communications and Chapter 12: Installation in this document for additional details regarding meter requirements.

Load Following mode utilizes MicroTurbine power in excess of the base power supplied by the utility grid (when required by external loads), allowing the MicroTurbine to track local electrical loads, and supplying only as much power as is required. The MicroTurbine regulates the utility power flow to an adjustable maximum - the utility power setpoint. If the local demand rises above this level by an adjustable amount for a selected time period, the MicroTurbine is dispatched to supply the difference (up to its capacity). Figure 4-4 illustrates how a MicroTurbine may be utilized in Load Following mode. In this illustration, the MicroTurbine package supplies power above a utility power setpoint of 1500 kW, up to its maximum power generation capability. Note that when actual load requirements fall below the 1500 kW utility setpoint, the MicroTurbine package stops producing power.

When setting up an external power meter, a Modbus slave compatible digital power meter is preferred for optimal load following control. Pulse type meters can only be accommodated with custom PLC logic. The system can avoid the export of MicroTurbine power to the utility grid with the correct load following settings. Refer to Chapter 9: Protective Relay Functions in this document for details. Refer to Appendix A: C1000 Modbus Register List for more information on Modbus communication.

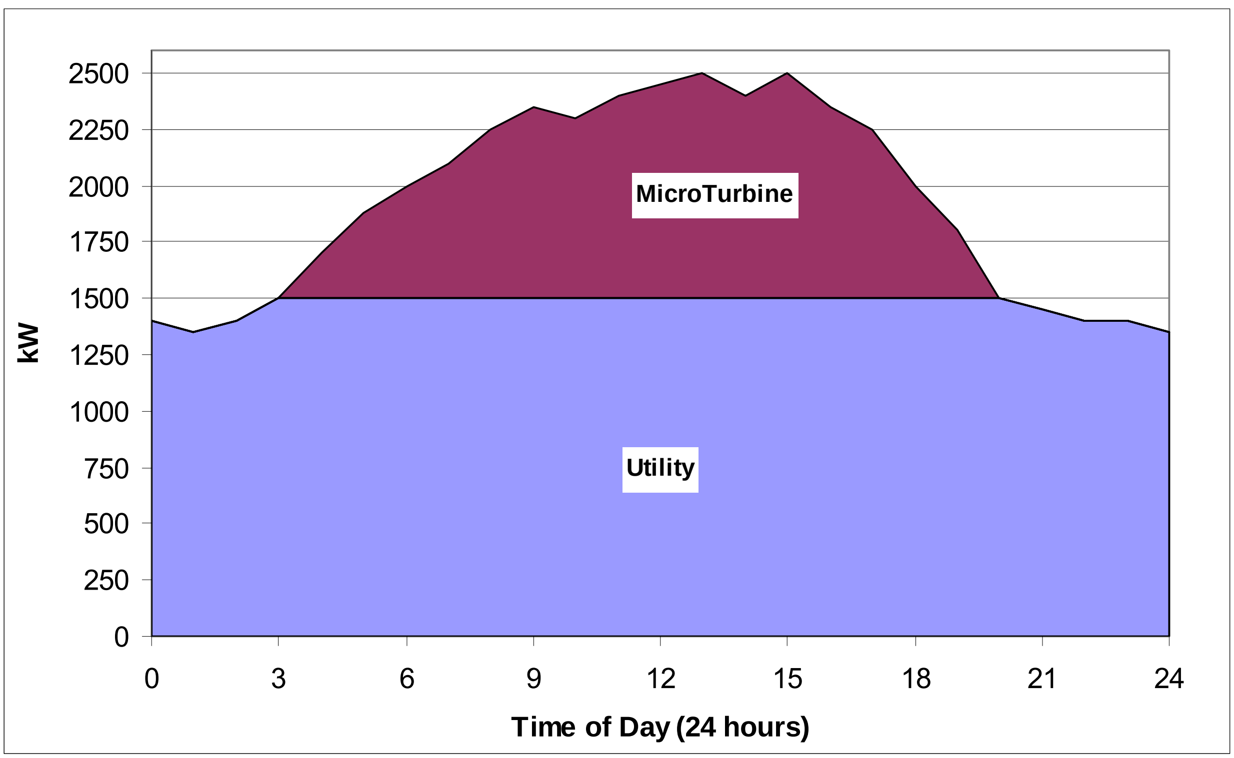


Figure 4-4. Grid Connect Operation in Load Following Dispatch Mode

The Load Following mode is used in the following situations: 1) To reduce peak demand charges (where applicable), 2) When power draw from the utility grid is limited by supply equipment capacity, or 3) If installed MicroTurbine capacity exceeds the minimum local load demand and net revenue metering is not allowed by the utility.

Configuring Load Following mode requires a PC with CRMS software. The parameters that need to be configured using CRMS are as follows:

- Utility Power Setpoints adjust the allowable upper and lower utility power limits as measured by the external power meter.
- Response Time sets the required time before the system responds with a new output command based on power meter signals. This acts as a filter to smooth out transients.
- Minimum Power Shutoff assigns an allowable power limit below the Utility Power Setpoint (based on kW demand) that the MicroTurbine will operate before shutting down.
- Minimum Power Start-Up assigns a minimum power limit for the turbine to turn on (based on kW demand) if the system load exceeds the Utility Power Setpoint. This parameter is intended to maximize system efficiency by allowing the utility grid to continue operation instead of the MicroTurbine at lower power levels. Together with the Minimum Power Shutoff, this setting provides a deadband to avoid frequent start-ups and shutdowns of the MicroTurbine.
- Meter Constant specifies the number of watt-hours represented by a single pulse signal from the external power meter.

Refer to the CRMS Technical Reference User Edition (410013) for how to configure these settings. As with other operational modes, CRMS-APS is used to configure the C1000 controller, which then dispatches required power commands to the constituent power modules.

Dispatch Modes

The sections above have defined the two operating modes (Grid Connect and Stand Alone) and the options available for determining a power demand set-point. The power produced during MicroTurbine operation can be dispatched through a number of control modes. The dispatch or operational mode determines the MicroTurbine power export set-point and how that power output requirement is allocated among the power modules within the C1000 MicroTurbine package.

Not all Dispatch modes will function with each operating mode. This section describes the capabilities of a single C1000 MicroTurbine package and the dispatch modes available through the C1000 controller. Refer to the Advanced Power Server User’s Manual (400011) for details on the additional dispatch capabilities available when operating a MultiPac of Capstone MicroTurbines (any MultiPac containing a C1000 MicroTurbine package requires an APS).

The C1000 controller includes three control modes as described below. For each mode, the C1000 controller calculates the maximum power capability of the C1000 package based on the current operating conditions. This feature allows the C1000 controller to correct for reduced package power output and prevents the overloading of any power module in the C1000 package.

Load Balancing

A power demand is provided to the C1000 controller and this demand is allocated evenly among all enabled power modules in the C1000 package. This mode is available for Grid Connect or Stand Alone groups. Lower power demands may result in a lower efficiency due to the low power demand on each MicroTurbine power module in the C1000 package. Engine response to power demand changes will tend to be high, as each partially loaded engine in the C1000 package is able to increase power output simultaneously. Most applications will prefer the Maximum efficiency mode below.

Efficiency Optimization Modes and Spinning Reserve

The C1000 controller includes a number of features that take advantage of the multiple power modules used in C1000 packages to optimize MicroTurbine power generation efficiency while operating in both Grid Connect and Stand Alone modes. Efficiency optimization takes the required power demand and determines how many individual power modules must be operating to meet that demand. The power demand is then divided equally by the operating MicroTurbines. This allows some power modules to be shut down at lower power demands and increases the efficiency of the operating power modules by running them closer to full power.

The Efficiency Optimization mode will result in some units being shut down, resulting in less MicroTurbine modules being available to pick up increases in power demand. A value called “spinning reserve” is available and is used to ensure stable MicroTurbine operation even when the efficiency optimized MicroTurbine package is challenged with fast power demand changes. This value acts as an imaginary power demand and should be set to the approximate value of the expected maximum power demand change.

When the spinning reserve value is added to the actual power demand, the result is used to determine the number of operating MicroTurbines required. The actual power demand is then divided by the number of operating MicroTurbines in order to set the individual power demands for each MicroTurbine unit. This ensures that a demand change equal to the spinning reserve setting can be accommodated without the starting of an additional turbine, for a faster power response and more stable operation. The faster response to changes in power demand comes at a small cost to overall system efficiency, the spinning reserve can result in additional power modules being used to share the power demand.

Efficiency Optimization must be enabled or disabled through CRMS-APS and the spinning reserve value can be changed remotely over Modbus, through the C1000 controller display or through CRMS-APS, just as the power demand setting can be provided in remote or user modes. More information on this feature is available in the Advanced Power Server User’s Manual (400011), as the features functionality is identically implemented in that product.

Power Setpoint

This mode of operation allows the user to set up a manually configured maximum efficiency operation scheme by entering the On and Off setting for each power module in the C1000 package. This is accomplished by using four settings for each turbine as follows:

- On Power Threshold
- Off Power Threshold
- On Time Delay
- Off Time Delay

Using this control mode, the user sets up the power levels at which each individual power module in the C1000 package turns on and off. A power module that is not available for dispatch can be bypassed. This operating mode is only available for Grid Connect operation.

Thermal Priority

In some applications, the exhaust energy of the C1000 package will be used in a Heat Recovery Module (HRM) or a Combined Heat, Cooling and Power (CCHP) system. Thermal priority allows the C1000 package power export setting to be determined by the needs of the heat recovery system. In this mode, the C1000 controller increases the power demand on the unit until the heat recovery system is supplied with enough heat. This mode of operation is compatible with Maximum Efficiency mode and can only be used in Grid Connect operation.

NOTE	Not all features are available with all operating modes. Additionally, not all operating modes are compatible with both the Stand Alone and Grid Connect configurations. Table 4-1 below defines the allowable combinations of all of the modes, settings, and features.

Table 4-1. C1000 Controller Operating Features vs. Operational Modes

Operating Features and Settings	Grid Connect	Stand Alone
Load Balancing	Yes	Yes
Power set-point	Yes	No
Maximum Efficiency	Yes	Yes
Thermal Priority	Yes	No
Time of Use	Yes	Yes

Manual and Remote Operation

The C1000 controller includes a full featured touch screen local Graphical User Interface (GUI) that provides full functionality for local manual operation. See Figure 4-5. While CRMS-APS may be required for initial set-up, day to day commands can be issued from the unit's touch screen. The touch screen allows the user to input a power set-point, spinning reserve set-point (Stand-Alone modes only) and allows MultiPac capabilities to be enabled or disabled as well as unit starts and stops. Basic monitoring of unit status is also provided, including power output, power meter reading and C1000 I/O. See the C1000 Operating Manual for more information on the use of this interface.

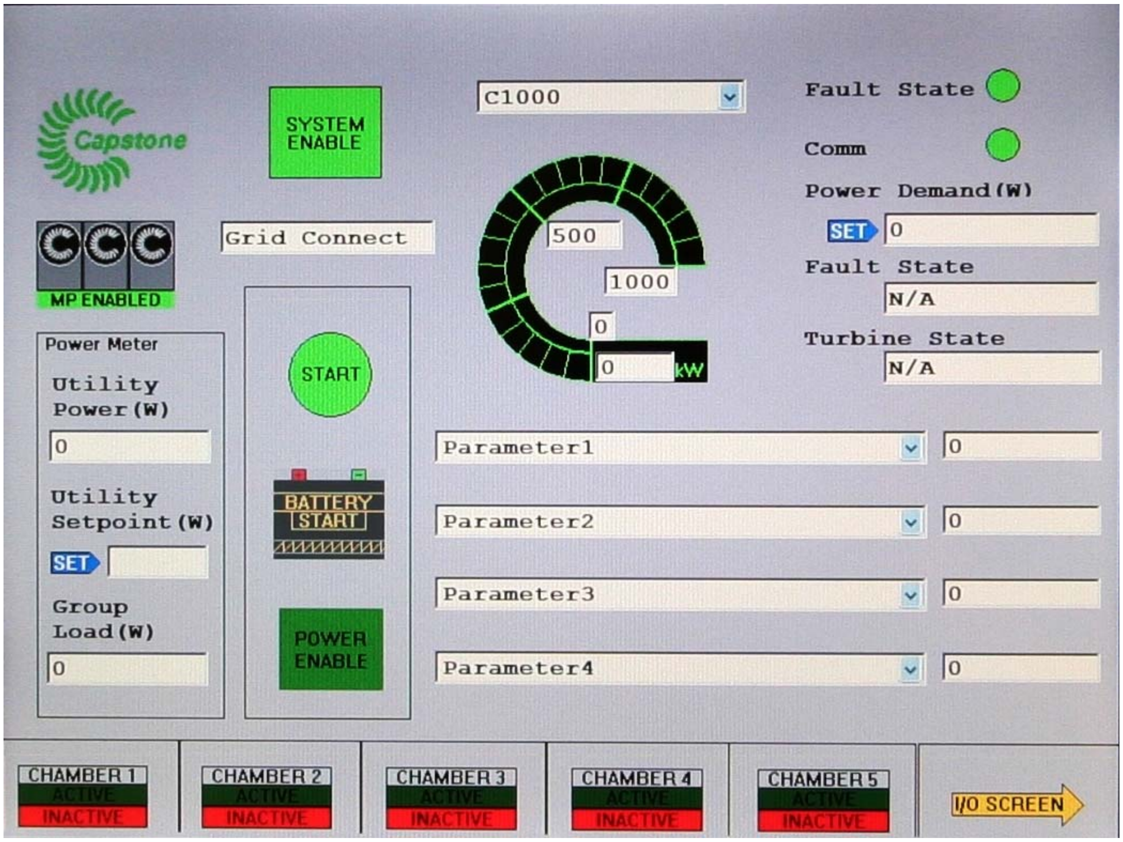


Figure 4-5. C1000 Controller Touch Screen Display

Most users will require some sort of remote operation or remote automation and interface with supervisory systems. The C1000 controller includes Modbus communication protocols for easy integration into supervisory station control systems and Building management systems. Most C1000 functionality is available over the Modbus communications link. Refer to Appendix A: C1000 Modbus Register List. Refer to Chapter 10: Communications for more information about remote communication with the C1000 controller.

The C1000 controller can also be optionally configured to accept hardwire commands for remote control and interface with supervisory systems that lack Modbus capabilities. The included PLC in the C1000 control packages can be supplied with additional I/O to accommodate custom remote control needs, please consult your Capstone Authorized Distributor for more information.

CHAPTER 5: BATTERY MANAGEMENT

Battery management for the two large battery packs used in each 200 kW power module in dual mode systems consists of two activities: Battery Charge Management maintains the desired state of charge (SOC) during operation and Equalization Charging of the battery packs optimizes the life of the battery pack. Battery Charge Management is an integrated function of the MicroTurbine control system that does not require any user input, but Equalization Charging does require user input. The following section will explain how Battery Management functions and user operating and maintenance requirements.

In Stand Alone operation, the primary functions of the battery are:

- Provide power during onload transients
- Accept power during offload transients
- Provide power while starting and stopping the MicroTurbine
- Provide power during standby state.

Battery performance is tied to regularly scheduled maintenance and equalization charging to optimize battery life and ensure that the battery performs as designed. Refer to the Battery Life section of Chapter 11: Maintenance for recommended preventive maintenance.

Battery Charge Management

Upon a Start command, the 200 kW power module leaves the Standby state to power up MicroTurbine components to operational levels before transitioning to the Run state, where battery charging may again occur. Once started in Stand Alone mode, the MicroTurbine will not advance to the Stand Alone Load state until the battery state-of-charge is at least 60% (note that state-of-charge less than 60% will only occur under conditions of poor maintenance, multiple subsequent fault cycles or end of battery life). After the 60% SOC is reached, the output contactor is closed and the MicroTurbine begins producing usable power.

The MicroTurbine system is designed to keep the battery at 95 to100 percent state-of-charge during Load state operation to allow for sourcing power for load transients. If a user-initiated STOP is performed, the system immediately enters the recharge state, to ensure the battery is over 90 percent state-of-charge before entering the cool-down state. Normally, the system will take approximately twenty (20) minutes to recharge the battery following a STOP command. On transition to cool-down, fuel is commanded off and the MicroTurbine spins down, but remains rotating to provide airflow over engine components for cooling. After cool-down is complete, the MicroTurbine enters a short Shutdown state before finally entering the Standby state. No battery charging is performed while in Standby.

If the system is not commanded ON during a user-selectable time period, the system will automatically enter a minimum battery drain state called Sleep state. This time period is called the Auto Sleep Time. Putting the battery in Sleep state can preserve battery charge for up to six months (life is based on ambient temperatures). Refer to the CRMS Technical Reference User Edition (410013) for how to set the Auto Sleep Time.

Note that the batteries must be at least 90% state-of charge for the system to achieve the full Stand Alone step load capabilities defined in Chapter 8: Electrical Ratings. Perform an equalization charge (next section) prior to commanding the system to the Stand Alone Load state if the application requires maximum step load capability.

Equalization Charge

The MicroTurbine will perform an equalization charge cycle periodically to maintain an equal charge in all battery cells (charges the battery packs to 100%). This equalization charge may be automated or commanded manually and may take up to four hours. Equalization charging may be disallowed during certain hours of certain days of the week to prevent interference with dispatch schedules.

In Stand Alone mode, the software will automatically initiate an equalization charge based on watt-hours usage of the battery pack. For full time Stand Alone operation, this occurs approximately once per week. A small amount of power produced by the MicroTurbine is provided to the battery pack to bring it up to 100 percent state-of-charge. Note that this power is not available to output loads, and the user may program allowable times for this charge to take place.

In Dual Mode configuration, the system will automatically initiate the equalization charge during the Grid Connect Load state every 7 to 30 days based on the Grid_Batt_Eq_Chg_days value. If an equalization charge is required, the system will initiate a battery wake-up, perform the 4-hour charge, and then put the battery pack back into sleep mode. If a charge is not required, the system will put the battery into sleep mode after 15 minutes in the Grid Connect Load state. As set by the factory, charging is allowed any time of the day. Days or times should be reduced to prevent charging from occurring during peak demand times. A minimum of one 4-hour window during MicroTurbine operating hours is required to maintain battery life.

NOTE	Once an equalization charge has started, it will complete regardless of the day and hour of the permission set-up.

C1000 Controller UPS Battery Management

In a Dual Mode system, the Uninterruptible Power Supply (UPS) provides the C1000 controller with uninterrupted power during normal operation and the flexibility to switch its power off when not required. The UPS is only installed in a C1000 Controller that is configured for Dual Mode operation. In Dual Mode, the UPS power system facilitates the Fast Transfer timer from Grid Connect to Stand Alone. Refer to the Dual Mode System Controller Technical Reference (410071) information about the Fast Transfer function. The following paragraphs describe the battery management process of the UPS in the C1000 controller. Refer to Figure 5-1 for an operational flow chart.

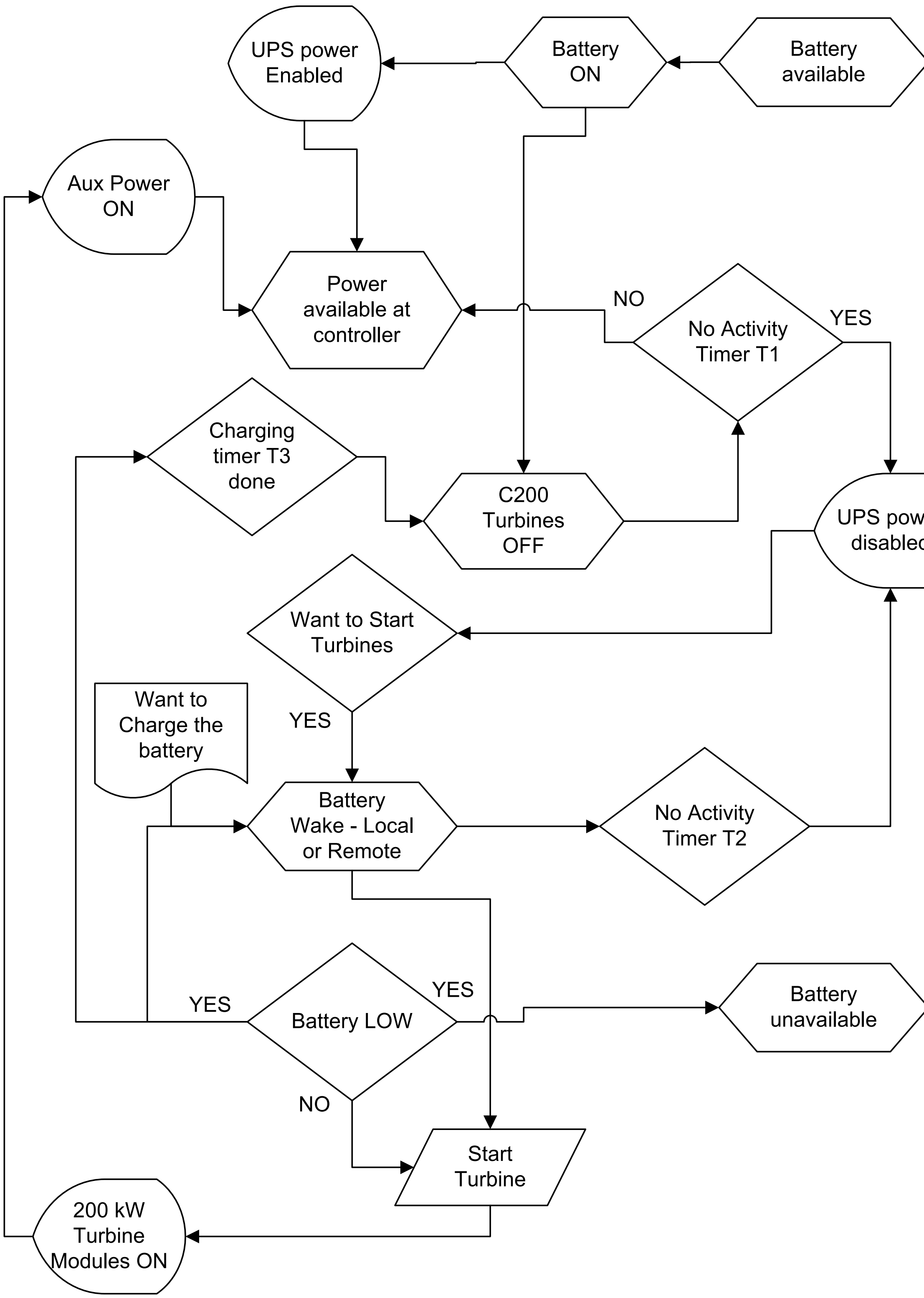


Figure 5-1. C1000 Controller UPS Battery Management

During Stand Alone operation, a power converter (480-24 VDC) from the Auxiliary AC bus supplies 24 VDC to the C1000 controller components. When all of the turbine modules are down, the UPS battery takes over. The UPS uses two timers for the battery wake-up and turbine start functions: sleep timer T1 and turbine start timer T2. Timer T1 starts when the UPS Battery On contact is activated. If the UPS does not receive a battery wake-up command within the time set by T1, the UPS switches off the battery. If the UPS receives a battery wake-up command, either locally by the push button on the C1000 controller or remotely, before T1 times out, it will disable T1 and the battery will remain on.

Upon a successful battery wake-up, the UPS starts timer T2, which sets the time during which the turbine modules must be started. If the turbines are started within this time period, the C1000 controller begins receiving power from the 24 VDC power converter, and the UPS switches off the battery.

Recharging of the UPS battery is initiated by feedback on the UPS Low Battery contact. This commands a battery wake-up and issues a turbine start command. It also starts timer T3, which sets the time period for the turbines to be on. After timer T3 times out, the turbines turn off. During the time that the turbines are on and the C1000 controller is receiving power from the Auxiliary AC, the UPS battery recharges.

CHAPTER 6: FUEL REQUIREMENTS

Capstone 1000 MicroTurbine systems are available in several versions that can operate on natural gas, and medium BTU gasses (such as from a landfill or anaerobic digester). Capstone has defined these fuel types according to energy content, Wobbe index, and other characteristics in the Fuel Requirements Specification (410002). Table 6-1 summarizes the energy content and inlet fuel pressure requirements for each C1000 package fuel version.

Table 6-1. Fuel Input Requirements

Fuel Type	Inlet Pressure Range	Fuel Type	Fuel Energy Content Range [HHV]
High Pressure NG	75 - 80 psig (517 – 552 kPaG)	Natural Gas	30,700 – 47,500 kJ/m^3 (825 – 1,275 Btu/scf)
Low Pressure NG	0.25 – 15 psig (1.8 – 103 kPaG)		
Landfill	75 – 80 psig (517 – 552 kPaG)	Landfill Gas	13,000 – 22,300 kJ/m^3 (350 – 600 Btu/scf)
Digester	75 – 80 psig (517 – 552 kPaG)	Digester Gas	20,500 – 32,600 kJ/m^3 (550 – 875 Btu/scf)

The fuel provided to each C1000 package must meet the inlet pressure requirements under all operating conditions. Fuel flow during on-loads can be up to twice the nominal steady state value. Nominal steady state fuel flow [HHV] at full power and ISO conditions for each 200 kW power module is 2,400,000 kJ/hr (2,280,000 Btu/hr). The ratio of higher heating value (HHV) to lower heating value (LHV) is assumed to be 1.1 for all fuel types.

Maximum fuel contaminants are defined in the Fuel Requirements Specification (410002) for each fuel type. Some of the allowable contaminants depend on the specific MicroTurbine model rather than the fuel type definition. For the 200 kW power modules, the maximum allowable sulfur content (expressed as hydrogen sulfide) is shown in Table 6-2.

Table 6-2. Maximum Sulfur Content

Fuel Type	Maximum Sulfur Content (expressed as H_2S)
High Pressure NG	5 ppm
Low Pressure NG	
Landfill	5,000 ppm
Digester	5,000 ppm

The Landfill/Digester Gas Use Application Guide (480002) contains advice and examples for designing fuel treatment systems for landfill and digester gas applications. In addition to this specific guidance, Table 6-3 summarizes the requirements to be met at the inlet to each MicroTurbine for all fuel types.

Table 6-3. General Fuel Requirements for All Fuel Types

Fuel Characteristic	Requirement
Maximum Temperature	50°C (122°F)
Minimum Temperature	Greater of 0°C (32°F) or 10°C (18°F) above fuel dew point
Inlet Pressure Fluctuations	< 1 psi/sec (1)
Particulates	95% of particulates and vapors < 10µm (2)
Lubricating Oils (e.g. from external compressor	none

Notes:

(1) Capstone recommends a regulator be provided at the C1000 package inlet to minimize pressure disturbances in a common fuel header for all high pressure systems. Note that the inlet pressure ranges in Table 6-1 are after the addition of any regulator.

(2) Capstone recommends the use of an external fuel filter in most cases. A common filter for a header feeding all MicroTurbines is acceptable. Use a 10 µm or finer filter element. A filter may not be required for U.S. installations using commercial natural gas.

The C1000 MicroTurbine package must be set up with the correct fuel settings for the specific fuel type. Factory settings are adjusted for the nominal fuel type. A Capstone Authorized Service Provider can make field setting changes, if necessary, using CRMS-APS.

Refer to the C1000 Outline & Installation drawing (524341) for fuel inlet connection details. All fuel types have a single 4 inch 150# ANSI RF flanged fuel inlet connection located on the same side of the package as the C1000 controller and electrical connections.

CHAPTER 7: PERFORMANCE

The information in this section is intended to provide guidance for estimating the performance characteristics of Capstone C600, C800 and C1000 MicroTurbines under different operating conditions of temperature, elevation, load, inlet restriction, and exhaust back pressure.

Power Output

Gas turbines are often called mass flow devices due to the fact that they take in significantly more air than is required for stoichiometric combustion. This results in a thermodynamic cycle that is dependent on air density effects of temperature and elevation. MicroTurbine systems have been designed with this characteristic in mind, and the size and capability of the generator and associated power electronics are matched to the micro gas turbine output. The industry standard for gas turbines is to publish their nameplate-rated output based on ISO condition of 15°C (59°F) and 60% relative humidity at sea level. Capstone MicroTurbines take the high frequency output of the generator that is connected to a common shaft with the gas turbine power section and use power electronics to rectify it to DC, and then invert back to useable AC power at 50 or 60Hz. Since the generator windings and power electronics outputs are limited by their current carrying capacity, the net MicroTurbine power output is typically maintained at some maximum level as temperature decreases, even though the gas turbine could produce additional power. Figure 7-1 shows an example of the published power output of a Capstone 200 kW MicroTurbine power module as a function of temperature.

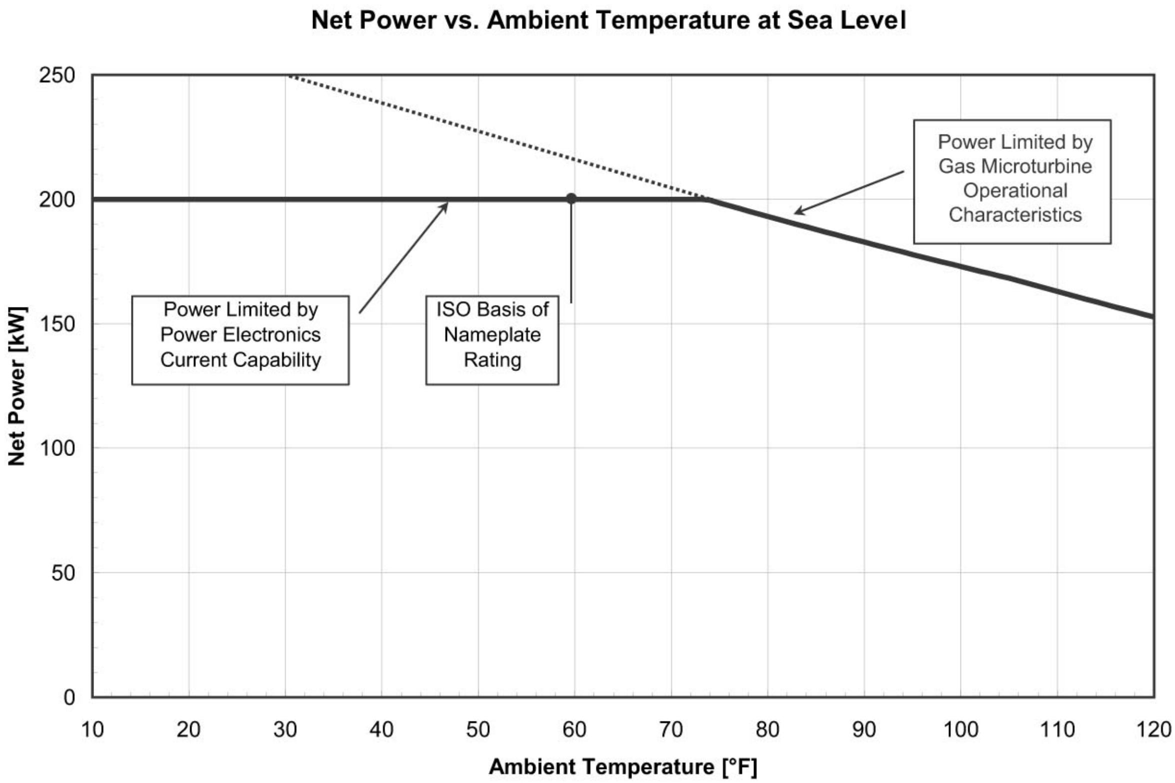


Figure 7-1. Net Power vs Ambient Temperature

Efficiency and Fuel Heating Value

Gas turbines generate mechanical power by combusting fuel to expand incoming air to drive a power turbine wheel. The recuperator in the Capstone MicroTurbine transfers some of the energy in the exhaust leaving the power turbine section to preheat incoming compressed air, thereby reducing the amount of fuel needed to expand the air driving the turbine. This results in nearly double the unrecuperated efficiency. The exhaust leaving the recuperator is still at sufficiently high temperatures that the products of combustion remain in vapor state.

The products of combustion for a hydrocarbon fuel are carbon dioxide (CO_2) and water (H_2O). The heating value of the fuel used in any engine can be calculated two ways:

1. Lower Heating Value – the energy associated with condensation of water vapor is not considered.
2. Higher Heating Value – the energy of water condensation taken back to ambient temperature is added to the lower heating value of the fuel.

Since the MicroTurbine exhaust never gets cool enough to condense water and take advantage of that additional energy of condensation, the industry standard is to use the lower heating value when calculating efficiency. This is typical for all prime movers, whether turbines, reciprocating engines, or fuel cells. When purchasing fuel, however, the total available energy content is usually referenced; meaning the higher heating value. This technical reference may provide information in either unit of measure, but will always signify whether it is lower heating value (LHV) or higher heating value (HHV). For gaseous fuels, the ratio of higher heating value to lower heating value is assumed to be 1.1.

Heat rate is an industry standard term for the amount of energy input for a unit electrical output, and is often shown in British Thermal Units (BTUs) per kilowatt-hour of electrical output. There are 3,413 BTUs per kWh. The net heat rate is defined as electrical output (kWh) at the user terminals of the MicroTurbine package. The generator heat rate is based on the electrical output at the generator terminals, prior to the digital power electronics.

Fuel Parameters

Refer to Chapter 6: Fuel Requirements for detailed information regarding fuel parameters for the Model C600, C800 and C1000 MicroTurbines.

Exhaust Characteristics

The exhaust information included in this section represents nominal temperature, mass flow, and energy. Any fluid passing through a confined space (such as hot exhaust moving through a duct or heat exchanger) will have some distribution of velocity and temperature. Testing using probes for temperature or mass flow will therefore show differences, depending on where in the flow the measurements are taken. The values in this section should therefore be considered averages across the exhaust outlet of the MicroTurbine. The exhaust energy is calculated without considering the energy of condensation, and is therefore based on lower heating value.

Each MicroTurbine power module control system uses turbine exit temperature (TET) as part of its control function, and attempts to maintain TET to a preset value for most operating conditions. The exhaust at the MicroTurbine outlet is lower than this TET, since some energy has been extracted in the recuperator to preheat incoming compressed air. As a simple approximation, turbine efficiency depends on ambient temperature therefore, the higher the efficiency the lower the exhaust temperature. Efficiency does not change significantly with change in elevation. Therefore, to estimate exhaust characteristics at elevation, consider the exhaust temperature to be the same as for a given temperature at sea level and adjust the mass flow rate to reflect changes in power output. More details on how to calculate exhaust characteristics are described below.

ISO Full Load Performance

A summary of nominal performance at full load power and ISO conditions for Capstone C600, C800 and C1000 MicroTurbine packages is shown in Table 7-1.

Table 7-1. Capstone Model C1000 MicroTurbine Performance Summary

Parameter	C600		C800		C1000	
	Low Pressure NG	All Other	Low Pressure NG	All Other	Low Pressure NG	All Other
Net Power Output	570 +0/-12 kW net	600 +0/-12 kW net	760 +0/-16 kW net	800 +0/-16 kW net	950 +0/-20 kW net	1000 +0/-20 kW net
Net Efficiency (LHV)	31 ±2%	33 ±2%	31 ±2%	33 ±2%	31 ±2%	33 ±2%
Nominal Net Heat Rate (LHV)	11,600 kJ/kWh (11,000 Btu/kWh)	10,900 kJ/kWh (10,300 Btu/kWh)	11,600 kJ/kWh (11,000 Btu/kWh)	10,900 kJ/kWh (10,300 Btu/kWh)	11,600 kJ/kWh (11,000 Btu/kWh)	10,900 kJ/kWh (10,300 Btu/kWh)
Nominal Generator Heat Rate (LHV)	10,700 kJ/kWh (10,200 Btu/kWh)	10,200 kJ/kWh (9,700 Btu/kWh)	10,700 kJ/kWh (10,200 Btu/kWh)	10,200 kJ/kWh (9,700 Btu/kWh)	10,700 kJ/kWh (10,200 Btu/kWh)	10,200 kJ/kWh (9,700 Btu/kWh)
Nominal Steady State Fuel Flow (HHV)(1) (2)	7,200,000 kJ/hr (6,840,000 BTU/hr)		9,600,000 kJ/hr (9,120,000 BTU/hr)		12,000,000 kJ/hr (11,400,000 BTU/hr)	

Notes:

(1) The ratio of Higher Heating Value (HHV) to Lower Heating Value (LHV) is assumed to be 1.1.

(2) Onload fuel flows can be up to two times higher than the steady state values.

How to Use This Section

The following pages present several tables and graphs for determining the nominal net power output, efficiency, and exhaust characteristics for various operating conditions. The information in these tables is presented per 200 kW power module. For characteristics that must be scaled by the number of power module in use, the heading indicates that the value is “per module.” These factors must be multipled by the number of operational 200 kW.

For full power output of the C600 package, N=3 must be used, for C800 N=4 and for C1000 N=5. N values of 1 and 2 can also be used to reflect application specific operational states or specific manifolding for heat recovery or other applications.

Table 7-5 at the end of this section provides an example calculation. The basic method is summarized below:

- Look up the efficiency, exhaust temperature, and exhaust mass flow for a given ambient temperature using Table 7-2. Keep in mind that exhaust mass flow must be multiplied by the number of operational modules.

- Estimate the power output using Figure 7-2 for a given temperature and elevation. This power output will be multiplied by the number of operating units.
- Apply inlet pressure loss power and efficiency correction factors (if any) using Table 7-3. The power correction is dimensionless and requires no modification based on the number of operational power modules.
- Apply back pressure power and efficiency correction factors (if any) using Table 7-4. These are also dimensionless.
- Calculate nominal net power output and fuel input for the given operating conditions. The factors are presented per power module and must be multiplied by the number of modules in use.
- Define parasitic loads (Fuel Gas Booster, water pump, etc.), either for the system or for each power module.
- Estimate exhaust temperature and flow for the given operating conditions. Exhaust mass flow must be multiplied by the number of units in operation or the number of units manifolded for the application.

In addition to the steps above, tolerances for a given application must be considered. Refer to the Consider Tolerances section of this document for more information.

Ambient Temperature Table

Nominal net power output, efficiency, and exhaust characteristics versus ambient temperature at sea level for each Capstone 200 kW power module in the C1000 packages (high pressure natural gas model) are presented in Table 7-2. These values are estimated from nominal performance curves.

Table 7-2. Nominal Net Power Output and Efficiency versus Ambient Temperature

Ambient Temp (°F)	Net Power per module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (Btu/hr / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWhr LHV)
-4	200.0	34.3	431.9	3.04	375.1	1,991,249	9,956
-3	200.0	34.3	433.4	3.03	374.9	1,991,158	9,956
-2	200.0	34.3	434.9	3.03	374.8	1,991,069	9,955
-1	200.0	34.3	436.5	3.02	374.6	1,990,982	9,955
0	200.0	34.3	438.0	3.02	374.4	1,990,898	9,954
1	200.0	34.3	439.6	3.01	374.3	1,990,815	9,954
2	200.0	34.3	441.1	3.01	374.1	1,990,735	9,954
3	200.0	34.3	442.6	3.00	373.9	1,990,657	9,953
4	200.0	34.3	444.2	3.00	373.8	1,990,581	9,953
5	200.0	34.3	445.7	2.99	373.6	1,990,532	9,953
6	200.0	34.3	447.2	2.99	373.5	1,990,511	9,953
7	200.0	34.3	448.8	2.99	373.3	1,990,491	9,952
8	200.0	34.3	450.3	2.98	373.2	1,990,474	9,952
9	200.0	34.3	451.9	2.98	373.1	1,990,458	9,952
10	200.0	34.3	453.4	2.97	372.9	1,990,444	9,952
11	200.0	34.3	454.9	2.97	372.8	1,990,432	9,952
12	200.0	34.3	456.5	2.96	372.6	1,990,422	9,952
13	200.0	34.3	458.0	2.96	372.5	1,990,413	9,952
14	200.0	34.3	459.5	2.95	372.3	1,990,406	9,952
15	200.0	34.3	461.1	2.95	372.2	1,990,401	9,952
16	200.0	34.3	462.6	2.94	372.1	1,990,398	9,952
17	200.0	34.3	464.1	2.94	371.9	1,990,396	9,952
18	200.0	34.3	465.7	2.93	371.8	1,990,396	9,952
19	200.0	34.3	467.2	2.93	371.6	1,992,466	9,962
20	200.0	34.2	468.7	2.93	371.9	1,994,540	9,973
21	200.0	34.2	470.3	2.93	372.3	1,996,618	9,983
22	200.0	34.2	471.8	2.93	372.8	1,998,701	9,994
23	200.0	34.1	473.3	2.93	373.2	2,000,788	10,004
24	200.0	34.1	474.9	2.93	373.6	2,002,879	10,014
25	200.0	34.0	476.4	2.93	374.1	2,004,975	10,025
26	200.0	34.0	477.9	2.93	374.5	2,007,075	10,035
27	200.0	34.0	479.4	2.93	374.9	2,009,180	10,046
28	200.0	33.9	481.0	2.93	375.4	2,011,289	10,056
29	200.0	33.9	482.5	2.93	375.8	2,013,402	10,067
30	200.0	33.9	484.0	2.93	376.3	2,015,520	10,078
31	200.0	33.8	485.6	2.93	376.7	2,017,643	10,088
32	200.0	33.8	487.1	2.93	377.1	2,019,769	10,099
33	200.0	33.8	488.6	2.93	377.6	2,021,901	10,110
34	200.0	33.7	490.1	2.93	378.0	2,024,037	10,120
35	200.0	33.7	491.6	2.93	378.4	2,026,177	10,131
36	200.0	33.7	493.2	2.93	378.9	2,028,322	10,142
37	200.0	33.6	494.7	2.93	379.3	2,030,471	10,152

Table 7-2. Nominal Net Power Output and Efficiency versus Ambient Temperature (Cont)

Ambient Temp (°F)	Net Power per module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (Btu/hr / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWhr LHV)
38	200.0	33.6	496.2	2.93	379.7	2,032,625	10,163
39	200.0	33.5	497.8	2.93	380.2	2,034,784	10,174
40	200.0	33.5	499.6	2.93	380.9	2,036,947	10,185
41	200.0	33.5	501.5	2.93	381.6	2,039,114	10,196
42	200.0	33.4	503.3	2.93	382.3	2,041,287	10,206
43	200.0	33.4	505.1	2.93	383.0	2,043,464	10,217
44	200.0	33.4	507.0	2.93	383.7	2,045,645	10,228
45	200.0	33.3	508.8	2.93	384.4	2,047,832	10,239
46	200.0	33.3	510.7	2.93	385.1	2,050,023	10,250
47	200.0	33.3	512.6	2.93	385.8	2,052,218	10,261
48	200.0	33.2	514.4	2.93	386.5	2,054,419	10,272
49	200.0	33.2	516.3	2.93	387.3	2,056,624	10,283
50	200.0	33.2	518.2	2.93	388.0	2,058,834	10,294
51	200.0	33.1	520.1	2.93	388.7	2,061,048	10,305
52	200.0	33.1	522.0	2.93	389.5	2,063,268	10,316
53	200.0	33.0	523.9	2.93	390.2	2,065,492	10,327
54	200.0	33.0	525.8	2.93	391.0	2,067,721	10,339
55	200.0	33.0	527.8	2.93	391.8	2,069,954	10,350
56	200.0	32.9	529.7	2.93	392.5	2,072,193	10,361
57	200.0	32.9	531.6	2.93	393.3	2,074,436	10,372
58	200.0	32.9	533.5	2.93	394.0	2,076,693	10,383
59	200.0	32.8	535.1	2.93	394.6	2,078,942	10,395
60	200.0	32.8	536.8	2.93	395.1	2,081,198	10,406
61	200.0	32.8	538.4	2.93	395.6	2,083,460	10,417
62	200.0	32.7	540.1	2.93	396.2	2,085,727	10,429
63	200.0	32.7	541.7	2.93	396.7	2,088,000	10,440
64	200.0	32.7	543.4	2.93	397.2	2,090,278	10,451
65	200.0	32.6	545.0	2.93	397.8	2,092,560	10,463
66	200.0	32.6	546.6	2.93	398.3	2,094,848	10,474
67	200.0	32.5	548.2	2.93	398.8	2,097,141	10,486
68	200.0	32.5	549.9	2.93	399.3	2,099,439	10,497
69	200.0	32.5	551.5	2.93	399.8	2,101,742	10,509
70	200.0	32.4	553.1	2.93	400.3	2,104,050	10,520
71	200.0	32.4	554.8	2.93	400.9	2,106,362	10,532
72	200.0	32.4	556.5	2.93	401.5	2,108,680	10,543
73	200.0	32.3	558.2	2.93	402.1	2,111,004	10,555
74	199.7	32.3	559.7	2.93	402.5	2,110,939	10,572
75	198.6	32.2	560.6	2.93	402.5	2,102,499	10,589
76	197.4	32.2	561.5	2.92	402.1	2,094,133	10,606
77	196.4	32.1	562.4	2.92	401.3	2,085,842	10,623
78	195.3	32.1	563.3	2.91	400.5	2,077,624	10,640
79	194.2	32.0	564.2	2.91	399.7	2,069,477	10,657
80	193.1	32.0	565.1	2.91	398.9	2,061,398	10,675

Table 7-2. Nominal Net Power Output and Efficiency versus Ambient Temperature (Cont)

Ambient Temp (°F)	Net Power per module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (Btu/hr / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWhr LHV)
81	192.1	31.9	566.0	2.90	398.2	2,053,386	10,692
82	191.0	31.9	566.8	2.89	397.4	2,045,439	10,709
83	190.0	31.8	567.7	2.89	396.6	2,037,557	10,727
84	188.9	31.8	568.5	2.88	395.7	2,029,736	10,744
85	187.9	31.7	569.4	2.88	394.9	2,021,975	10,762
86	186.9	31.7	570.2	2.87	394.1	2,014,237	10,779
87	185.8	31.6	571.1	2.87	393.3	2,006,482	10,797
88	184.8	31.6	571.9	2.86	392.5	1,998,785	10,815
89	183.8	31.5	572.7	2.86	391.6	1,991,144	10,832
90	182.8	31.5	573.5	2.85	390.8	1,983,558	10,850
91	181.8	31.4	574.3	2.85	389.9	1,976,025	10,868
92	180.8	31.4	575.1	2.84	389.0	1,968,545	10,886
93	179.8	31.3	575.8	2.84	388.1	1,960,963	10,904
94	178.8	31.2	576.6	2.83	387.1	1,953,318	10,922
95	177.9	31.2	577.3	2.83	386.1	1,945,733	10,940
96	176.9	31.1	578.0	2.82	385.2	1,938,204	10,958
97	175.9	31.1	578.7	2.82	384.2	1,930,731	10,977
98	174.9	31.0	579.4	2.81	383.2	1,923,312	10,995
99	174.0	31.0	580.1	2.81	382.2	1,915,946	11,013
100	173.0	30.9	580.8	2.80	381.2	1,908,632	11,032
101	172.1	30.9	581.5	2.79	380.2	1,901,369	11,050
102	171.1	30.8	582.2	2.79	379.2	1,894,155	11,069
103	170.2	30.8	582.8	2.78	378.1	1,886,989	11,087
104	169.3	30.7	583.5	2.78	377.1	1,879,871	11,106
105	168.3	30.7	584.1	2.77	376.1	1,872,796	11,125
106	167.3	30.6	584.6	2.77	374.7	1,863,936	11,143
107	166.2	30.6	585.1	2.76	373.3	1,855,102	11,162
108	165.1	30.5	585.5	2.75	371.9	1,846,306	11,181
109	164.1	30.5	586.0	2.74	370.5	1,837,550	11,200
110	163.0	30.4	586.4	2.74	369.1	1,828,834	11,219
111	162.0	30.4	586.8	2.73	367.7	1,820,157	11,238
112	160.9	30.3	587.3	2.72	366.3	1,811,518	11,258
113	159.9	30.3	587.7	2.71	364.8	1,802,918	11,277
114	158.8	30.2	588.1	2.71	363.4	1,794,357	11,296
115	157.8	30.2	588.5	2.70	362.0	1,785,834	11,315
116	156.8	30.1	588.9	2.69	360.5	1,777,348	11,335
117	155.8	30.1	589.3	2.69	359.1	1,768,900	11,354
118	154.8	30.0	589.7	2.68	357.6	1,760,490	11,374
119	153.8	30.0	590.1	2.67	356.2	1,752,116	11,394
120	152.8	29.9	590.5	2.66	354.7	1,743,780	11,413
121	151.8	29.9	590.8	2.66	353.3	1,735,480	11,433
122	150.8	29.8	591.2	2.65	351.8	1,727,216	11,453

Elevation Derating

Elevation affects power output by changing the density of the air.

Figure 7-2 provides expected maximum power output for several elevations versus ambient temperature. Values shown assume nominal engine output, and are based on the 1976 US Standard Atmosphere model to correlate air density to elevation. Electrical efficiency is not strongly dependent on elevation, so the nominal efficiency values listed in Table 7-2 can be used to estimate fuel consumption at any elevation for a given ambient temperature. A method to estimate exhaust characteristics is provided below.

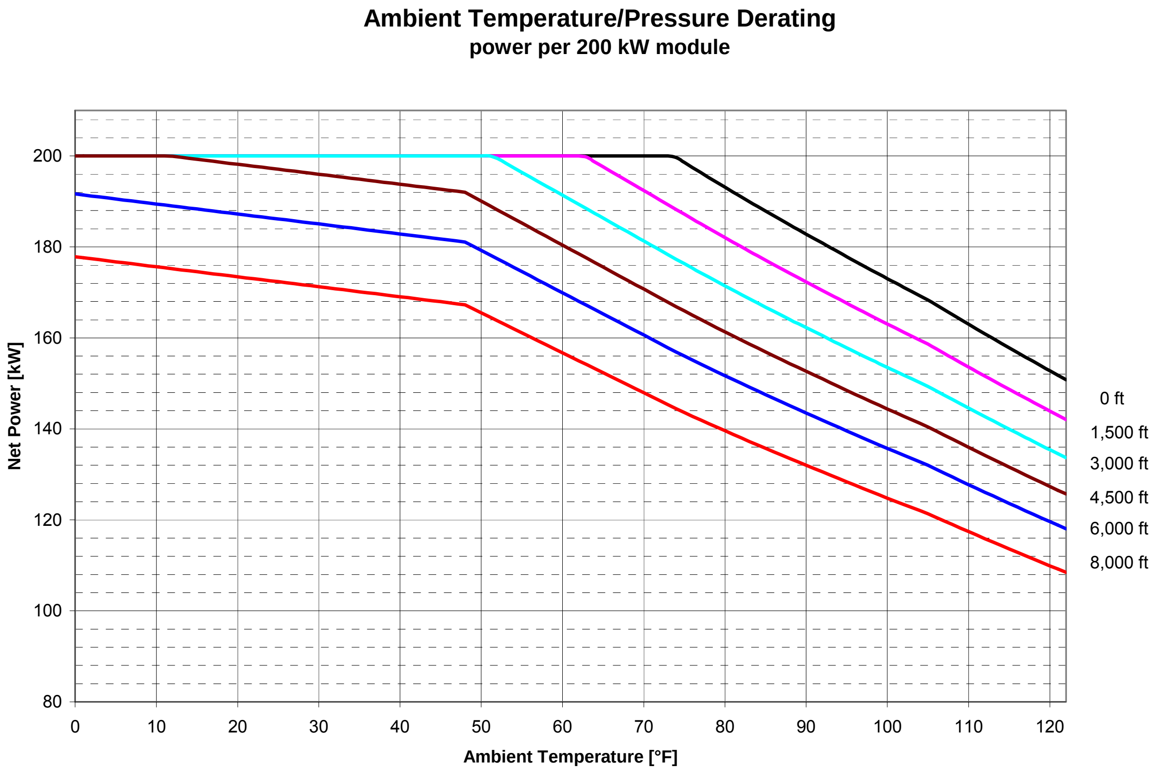


Figure 7-2. Elevation vs. Ambient Temperature Derating

Inlet Pressure Loss Correction Factors

Air inlet design can affect engine performance. The amount of air inlet filter debris can also affect engine performance for all engine applications. The maximum allowable inlet pressure loss is 10 inches of water.

Table 7-3 presents the nominal fraction of ISO zero inlet pressure loss power and efficiency versus inlet pressure loss at ISO ambient conditions for each Capstone 200 kW MicroTurbine power module. These values are estimated from nominal performance curves. Interpolate, if needed, for inlet pressure losses between those listed in Table 7-3.

The inlet loss power and efficiency correction factors are defined as follows:

$$\text{Power CF} = \frac{\text{Power Output}}{\text{Power Output at Zero (0) Inlet Loss}}$$

$$\text{Efficiency CF} = \frac{\text{Efficiency}}{\text{Efficiency at Zero (0) Inlet Loss}}$$

Table 7-3. Nominal Fraction of ISO Zero Inlet Pressure Loss Power and Efficiency

Inlet Pressure Loss (Inches of Water)	Inlet Pressure Loss Power CF	Inlet Pressure Loss Efficiency CF
0.0	1.000	1.000
1.0	0.994	0.998
2.0	0.987	0.995
3.0	0.981	0.993
4.0	0.974	0.990
5.0	0.968	0.988
6.0	0.961	0.986
7.0	0.955	0.983
8.0	0.949	0.981
9.0	0.942	0.978
10.0	0.936	0.976

Back Pressure Correction Factors

The maximum allowable exhaust back pressure for each Capstone 200 kW MicroTurbine power module is eight inches of water. Nominal fraction of ISO net power output and efficiency versus back pressure is presented in Table 7-4. These values are estimated from nominal performance curves. Interpolate, if needed, for back pressure values between those listed in Table 7-4.

The back pressure power and efficiency correction factors are defined as follows:

$$\text{Power CF} = \frac{\text{Power Output}}{\text{Power Output at zero (0) Back Pressure}}$$

$$\text{Efficiency CF} = \frac{\text{Efficiency}}{\text{Efficiency at zero (0) Back Pressure}}$$

Table 7-4. Nominal Fraction of ISO Net Power Output and Efficiency Vs Exhaust Back Pressure at ISO Ambient Conditions

Back Pressure (Inches of Water)	Back Pressure Power CF	Back Pressure Efficiency CF
0.0	1.000	1.000
1.0	0.996	0.998
2.0	0.992	0.995
3.0	0.988	0.993
4.0	0.985	0.990
5.0	0.981	0.988
6.0	0.977	0.985
7.0	0.973	0.983
8.0	0.969	0.981

Calculate Nominal Net Power and Fuel Input

The net power output can be estimated from previous steps by multiplying the inlet and exhaust back pressure correction factors times the estimated power output from Figure 7-2. For example, using

Figure 7-2 for 30 °C (86 °F) temperature and 1,500 ft elevation, the estimated nominal power output is 176 kW per Capstone 200 kW power module. If the inlet pressure loss is 2 inches of water column, then the power correction factor from Table 7-4 is 0.987. For a 3 inch water column back pressure drop, the correction factor from Table 7-4 is 0.988. Use the following equation to estimate the net power:

$$\text{kW (net)} = \text{kW (elevation \& temp)} \times \text{Inlet CF} \times \text{Back Pressure CF} \times N$$

Continuing the example, the 176 kW gross power output per module becomes a net power of 172 kW per power module after multiplying by the inlet and exhaust backpressure correction factors. For a C1000 package with 5 200 kW operating power modules, N=5 and C1000 net power = 5 x 172 = 860 kW.

A similar calculation can be done for efficiency. Referring to Table 7-2 and using the same ambient temperature of 30 °C (86 °F), the efficiency is tabulated as 31.7%. For an inlet pressure loss of 2 inches of water column, the efficiency correction factor from Table 7-3 is 0.995. For an exhaust backpressure of 3 inches of water column, the efficiency correction factor from Table 7-4 is 0.993. Use the following equation to estimate the net efficiency:

$$\text{Efficiency (net)} = \text{Efficiency (ambient temp)} \times \text{Inlet CF} \times \text{Back Pressure CF}$$

Continuing the example, the 31.7% gross efficiency becomes a net efficiency of 31.3% after multiplying by the inlet and exhaust correction factors. Net efficiency does not require scaling by the number of operating power modules.

The fuel input can now be estimated from the net power and efficiency using the following equation:

$$\text{Net Fuel Input [kW]} = \frac{\text{Net Power Output [kW]}}{\text{Net Efficiency [\%]}}$$

For the example given above with net output power (C1000 package with 5 operating modules) of 860 kW and net efficiency of 31.3%, the estimated fuel input is 2750 kW. To convert this to English units, multiply the kW of fuel times 3,413 BTU per kWh to get 9,370,000 BTU/hr.

Parasitic Loads

The impact of parasitic loads on useable power output should be considered. For the low pressure natural gas models, each 200 kW power module's internal fuel gas booster requires approximately 10 kW of power under most operating conditions. This is because it is always trying to maintain fuel inlet pressure to the turbine regardless of MicroTurbine output power requirements or inlet fuel pressure.

So for any estimated net power output, subtract 10 kW for each operating low pressure natural gas 200 kW power module in the C1000 package. Other values may need to be provided if an external gas compressor is used, or other system parasitic loads need to be considered. Using the example above for of 30 °C (86 °F) ambient, 1,500 ft elevation, and inlet and back pressure correction factors applied, the 172 kW net output per module becomes a useable power output for customer loads of 162 kW per module after subtracting 10 kW for a fuel gas booster. The C1000 package for low pressure fuel gas in these conditions can then supply net power 810 kW.

Estimate Exhaust Characteristics

The temperature and mass flow for the exhaust can now be estimated, using the information calculated above for net power plus the exhaust characteristics at sea level. The primary impacts to exhaust characteristics are ambient temperature (which impacts electrical efficiency) and net electrical output. A simple method to approximate the exhaust characteristics is to define the exhaust temperature as if the system were operating at sea level, and then make adjustments to the exhaust mass flow to reflect changes in the net electrical output due to elevation, inlet pressure loss, and exhaust backpressure. An additional reduction of 0.5 percent per 1,000 ft elevation should be added to the exhaust mass flow calculation.

So, for a given ambient condition use the following equations:

$$\text{Exhaust Temp (elevation)} = \text{Exhaust Temp (sea level)}$$

$$\text{Exhaust Flow (elevation)} = \text{Flow (sea level)} \times \frac{\text{kWe (elevation)}}{\text{kWe (sea level)}} \times \left[1 - \frac{0.005 \times \text{Elevation [ft]}}{1{,}000}\right]$$

For the example above at 30 °C (86 °F) and 1,500 ft elevation, the exhaust temperature from Table 7-2 is 570°F and exhaust flow is 2.87 lbm/s per power module. From Table 7-2 the electric power output at sea level is 187 kW per power module, and from Figure 7-2 the electric power output at 1,500 ft elevation is 176 kW. Using the equations above:

Exhaust Temp (elevation) = 570°F

Exhaust Flow (elevation) = 2.70 lbm/s per power module.

For a model C1000 MicroTurbine with 5 operating power modules (N=5) the Exhaust flow (elevation)=5 X 2.70 lbm/s = 13.5 lbm/s.

Example Calculations

Table 7-5 provides an example calculation for a C800 low pressure natural gas MicroTurbine operating at 30 °C (86 °F), 1,500 ft elevation, 2 inches WC inlet pressure loss, and 3 inches WC exhaust back pressure.

Table 7-5. Example Calculation for Nominal Power, Efficiency, and Exhaust Characteristics

Steps	Rule	Example
1. Define output power per module, efficiency, and exhaust characteristics (some per module) at ambient temperature and sea level	Use Table 7-2	For 86°F (30°C) Ambient: Output = 186 kW electric per module Efficiency = 31.7% Exhaust Temp = 570°F Exhaust Flow = 2.87 lbm/s per module
2. Estimate electric output at the given elevation	Use Figure 7-2	for 1,500ft Elevation: Output = 176 kW electric per module
3. Estimate Power and Efficiency Correction Factors for Inlet Pressure Loss	Use Table 7-3	for 2 inch WC: Power CF = .987 Efficiency CF = .995
4. Estimate Power and Efficiency Correction Factors for Exhaust Back Pressure	Use Table 7-4	for 3 inch WC: Power CF = .988 Efficiency CF = .993
5. Calculate Nominal Net Power Output	kW (net) = kW (step 2) X Inlet CF X Exhaust CF	For Example Above: kWnet = 172 kW per module
6. Calculate package Net Power	Multiply per module result by number of operating modules	For C800, N=4: kWnet = 4 X 172 = 688 kW
7. Calculate Nominal Net Efficiency	Efficiency (net) = Efficiency (step 1) X Inlet CF X Exhaust CF	For Example Above: Efficiency (net) = 31.3%
8. Calculate Fuel Input per module	Fuel [kW] = kW(net)/ Efficiency (net)	For Example Above: Fuel [kW] = 550 kW (or 1,880,000 BTU/hr) per module
9. Calculate Fuel input for package	Multiply per module result by number of operating modules	For C800, N=4: Fuel [kW] = 550 X 4 = 2200 kW (7,520,000 BTU/hr)
10. Consider Parasitic Loads	Subtract net parasitic loads, if any	For Low Pressure NG C800: Parasitic = 10 kW per module Useable Power = 162 kW per module or 648 kW net
11. Estimate Exhaust Characteristics	Temp = Temp from step 1 Flow = Flow from step 1 times kWnet/kW step 2 less .5% per 1,000 ft Elevation X number of operating modules	Exhaust Temp = 570°F Exhaust Flow = 2.7 lbm/s X 4 = 10.8 lbm/s

Consider Tolerances

The calculations described above provide a relatively simple method to estimate electrical output, fuel consumption, and exhaust characteristics for given operating conditions. These calculations are based on nominal values, and do not consider differences from MicroTurbine to MicroTurbine or the measurement inaccuracies for each of the key parameters. The Capstone C1000 Product Specification (460051) provides curves showing minimum and maximum expected power and efficiency at sea level. A similar tolerance range of outputs can be expected for the impact of altitude and pressures. The following sections call out a suggested approach to using the performance information in this section.

Grid Connect Applications

When operating connected to a utility grid, Capstone MicroTurbines will always attempt to provide the set power demand. In the case where the set power demand is greater than what the MicroTurbine is able to produce, the MicroTurbine will provide the maximum that it can, given the specific operating conditions. This actual output may be above or below the nominal calculations defined above for that specific operating condition. For purposes of making economic projections, it is suggested that the nominal output be used, since this is what would be expected on average for a fleet of MicroTurbines.

Note that Capstone MicroTurbines operating in Grid Connect mode will generate real power (kW) at essentially unity power factor. This means that the apparent power (kVA) is equal to the real power (kW), and no reactive power is either provided to or taken from the utility grid in the standard configuration.

The inverter based power electronics employed in the load control module of the Capstone MicroTurbine package are also capable of delivering reactive power. This may be useful in correcting a facility's power factor if it is out of the utility's allowed range. In systems with this software feature the user can issue a reactive power set-point in grid connect mode. The real power demand will take priority over the reactive set point, as the MicroTurbine system is limited in the apparent power it is capable of delivering by the power electronics and operating conditions. If the reactive power set-point is desirable for your application, please contact Capstone Applications.

Stand Alone Applications

Stand Alone applications are more complicated than Grid Connect because only the MicroTurbines are being relied upon for load power. Each MicroTurbine will try to maintain its pre-set voltage, regardless of the connected loads. If the load is above the capability of the engine to provide continuous power, the batteries in the MicroTurbine will supply the shortfall in an attempt to keep the system running. If this overload condition continues, the batteries will ultimately be drained and the system will eventually shut down. It is therefore suggested that steady state loads be sized based on the following steps:

1. Worst Case Operating Environment – For a given site location, "nominal" power should be estimated based on the actual elevation, highest expected ambient temperature, and any other de-rating considerations such as for inlet pressure loss or exhaust back pressure and any parasitic loads.

2. Load Safety Margin – As would be normal practice for any Stand Alone prime mover, a reasonable amount of head room should be allocated to cover unexpected load increases and/or normal variation in load tolerances. Connected loads should therefore not be sized to exceed 80% of the unit nominal power output.

In Stand Alone mode, the C1000 MicroTurbine package is a voltage source and is able to generate real power (kW) according to the calculations above, as well as provide reactive power (kVAR) that the connected loads may require. The C1000 MicroTurbine package will try to provide total apparent power (kVA) up to the 310 Arms (per 200 kW power module) current limits of the power electronics. However, for design purposes, the power factor for the connected loads should not be less than 0.80 leading or lagging. Table 7-6 shows the respective maximum steady state currents at ISO conditions for different voltages.

Table 7-6. Maximum kVA and Current vs Voltage at ISO Conditions

	System Voltage	Real Power	Power Factor	Apparent Power	Maximum Steady State Current
200 kW power module	480 V line-to-line	200 kW	0.78 (1)	258 kVA	310 Arms
	400 V line-to-line	200 kW	0.93 (1)	215 kVA	310 Arms
C600	480 V line-to-line	600 kW	0.78 (1)	774 kVA	930 Arms
	400 V line-to-line	600 kW	0.93 (1)	645 kVA	930 Arms
C800	480 V line-to-line	800 kW	0.78 (1)	1032 kVA	1240 Arms
	400 V line-to-line	800 kW	0.93 (1)	860 kVA	1240 Arms
C1000	480 V line-to-line	1000 kW	0.78 (1)	1290 kVA	1550 Arms
	400 V line-to-line	1000 kW	0.93 (1)	1075 kVA	1550 Arms

Note:

(1) Current is limited by power electronics capability, and power factor is limited by maximum current

ISO Partial Load Performance

Refer to

Table 7-7 for performance data, per 200 kW power module, for C1000 high pressure natural gas MicroTurbine systems at partial load and ISO conditions. These values are estimated from nominal performance curves. Performance for biogas models is also predicted using these tables, but biogas power modules are not designed to operate below 100kW net power output (and are therefore only available in grid connect configurations). Performance of the low pressure natural gas models can be estimated from Table 7-7 by first accounting for the parasitic loss of the compressor. As previously indicated, parameters such as exhaust temperature, exhaust mass flow, and fuel flow energy rate, are determined prior to the deduction of the compressor's parasitic load. For a given net output power these performance characteristics can be estimated by using the performance values corresponding to the net output power plus 10 kW.

In determining the part load performance of the C1000 MicroTurbine systems, the operating mode must be taken into consideration. A single net power output can be dispatched in many different ways from the 3, 4, or 5 200 kW power modules in the package. See Chapter 4: Operating Modes, Dispatch Modes for more detail on the ways a power set-point can be delivered.

In short, the power output can be achieved either by running each operating power module at the same power or by optimizing efficiency by running a number of the modules at full power and the remaining modules at partial load or idle. If Maximum efficiency mode is used to reach a partial load power output for the package, overall electrical efficiency will have to be calculated by using a weighted average of the efficiencies and power outputs of the modules that are running. See the example calculation that follows.

Table 7-7. Partial Load Performance at ISO Ambient Conditions

Net Power per 200 kW module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (kW / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWh LHV)
15	13.6	326.7	0.97	69.8	375,455	25,030
16	14.2	328.4	0.99	71.4	384,351	24,022
17	14.8	330.1	1.00	73.0	392,872	23,110
18	15.3	331.9	1.02	74.7	402,481	22,360
19	15.8	333.6	1.03	76.5	412,009	21,685
20	16.2	335.3	1.05	78.2	421,460	21,073
21	16.7	337.0	1.07	79.9	430,836	20,516
22	17.1	338.6	1.08	81.6	440,141	20,006
23	17.5	340.2	1.10	83.3	449,378	19,538
24	17.9	341.8	1.11	84.9	458,550	19,106
25	18.3	343.3	1.13	86.6	467,658	18,706
26	18.6	344.8	1.14	88.2	476,706	18,335
27	19.1	346.1	1.15	89.6	484,231	17,934
28	19.4	347.6	1.17	91.2	493,451	17,623
29	19.7	349.0	1.18	92.9	502,626	17,332
30	20.0	350.5	1.20	94.5	511,758	17,059
31	20.3	351.9	1.21	96.2	520,866	16,802
32	20.6	353.3	1.23	97.8	529,932	16,560
33	20.9	354.6	1.24	99.4	538,959	16,332
34	21.2	356.0	1.26	101.1	547,946	16,116
35	21.5	357.3	1.27	102.7	556,887	15,911
36	21.8	358.6	1.28	104.3	565,771	15,716
37	22.0	359.8	1.30	105.9	574,617	15,530
38	22.3	361.1	1.31	107.4	583,426	15,353
39	22.5	362.3	1.32	109.0	592,198	15,185
40	22.8	363.5	1.34	110.6	600,935	15,023
41	23.0	364.7	1.35	112.1	609,639	14,869
42	23.2	365.8	1.36	113.7	618,309	14,722
43	23.4	367.0	1.38	115.2	626,948	14,580
44	23.7	368.1	1.39	116.8	635,555	14,444
45	23.9	369.2	1.40	118.2	643,615	14,303
46	24.1	370.3	1.41	119.7	652,323	14,181
47	24.3	371.6	1.43	121.3	661,013	14,064
48	24.5	372.9	1.44	122.8	669,679	13,952
49	24.7	374.2	1.45	124.4	678,323	13,843
50	24.9	375.4	1.46	125.9	686,950	13,739
51	25.1	376.7	1.47	127.4	695,586	13,639
52	25.2	377.9	1.48	129.0	704,194	13,542

Table 7-7. Partial Load Performance at ISO Ambient Conditions (Cont)

Net Power per 200 kW module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (kW / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWh LHV)
53	25.4	379.1	1.50	130.5	712,777	13,449
54	25.6	380.3	1.51	132.0	721,335	13,358
55	25.8	381.4	1.52	133.5	729,869	13,270
56	25.9	382.6	1.53	135.0	738,381	13,185
57	26.1	383.6	1.54	136.4	745,739	13,083
58	26.3	384.8	1.55	137.9	754,460	13,008
59	26.4	386.0	1.56	139.5	763,213	12,936
60	26.6	387.2	1.57	141.1	771,953	12,866
61	26.7	388.4	1.58	142.6	780,681	12,798
62	26.9	389.6	1.60	144.2	789,396	12,732
63	27.0	390.7	1.61	145.8	798,098	12,668
64	27.1	391.9	1.62	147.3	806,788	12,606
65	27.3	393.0	1.63	148.9	815,465	12,546
66	27.4	394.1	1.64	150.5	824,234	12,488
67	27.5	395.2	1.65	152.0	832,781	12,430
68	27.6	396.3	1.66	153.6	841,419	12,374
69	27.8	397.4	1.67	155.1	850,044	12,319
70	27.9	398.5	1.68	156.7	858,657	12,267
71	28.0	399.6	1.70	158.2	867,256	12,215
72	28.1	400.6	1.71	159.8	875,842	12,164
73	28.2	401.7	1.72	161.3	884,416	12,115
74	28.3	402.7	1.73	162.9	892,977	12,067
75	28.4	403.7	1.74	164.4	901,525	12,020
76	28.5	404.8	1.75	165.9	910,060	11,974
77	28.7	405.8	1.76	167.5	918,582	11,930
78	28.8	406.8	1.77	169.0	927,091	11,886
79	28.9	407.8	1.78	170.5	935,588	11,843
80	29.0	408.7	1.79	172.0	944,072	11,801
81	29.1	409.7	1.80	173.5	952,385	11,758
82	29.2	410.7	1.81	175.1	960,913	11,718
83	29.3	411.6	1.82	176.6	969,427	11,680
84	29.4	412.6	1.83	178.1	977,927	11,642
85	29.5	413.5	1.84	179.6	986,413	11,605
86	29.5	414.4	1.85	181.2	994,885	11,568
87	29.6	415.4	1.86	182.7	1,003,343	11,533
88	29.7	416.3	1.87	184.2	1,011,811	11,498
89	29.8	417.2	1.88	185.7	1,020,294	11,464
90	29.9	418.2	1.89	187.3	1,028,766	11,431

Table 7-7. Partial Load Performance at ISO Ambient Conditions (Cont)

Net Power per 200 kW module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (kW / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWh LHV)
91	30.0	419.1	1.90	188.8	1,037,228	11,398
92	30.1	420.0	1.91	190.3	1,045,679	11,366
93	30.2	420.9	1.92	191.8	1,054,119	11,335
94	30.2	421.7	1.93	193.3	1,062,549	11,304
95	30.3	422.5	1.94	194.7	1,069,985	11,263
96	30.4	423.4	1.95	196.2	1,078,433	11,234
97	30.5	424.3	1.96	197.7	1,086,877	11,205
98	30.6	425.1	1.97	199.2	1,095,309	11,177
99	30.7	426.0	1.98	200.7	1,103,683	11,148
100	30.7	426.8	1.99	202.2	1,112,057	11,121
101	30.8	427.6	2.00	203.7	1,120,432	11,093
102	30.9	428.4	2.01	205.2	1,128,807	11,067
103	31.0	429.2	2.02	206.7	1,137,183	11,041
104	31.0	430.0	2.03	208.2	1,145,561	11,015
105	31.1	430.8	2.04	209.7	1,153,940	10,990
106	31.2	431.6	2.05	211.2	1,162,321	10,965
107	31.2	432.4	2.06	212.7	1,170,703	10,941
108	31.3	433.2	2.07	214.2	1,179,088	10,917
109	31.4	433.9	2.08	215.7	1,187,485	10,894
110	31.4	434.7	2.09	217.2	1,195,881	10,872
111	31.5	435.5	2.10	218.7	1,204,276	10,849
112	31.6	436.3	2.11	220.3	1,212,669	10,827
113	31.6	432.7	2.12	219.1	1,221,060	10,806
114	31.7	433.8	2.13	220.8	1,229,451	10,785
115	31.7	434.9	2.14	222.5	1,237,861	10,764
116	31.8	436.0	2.15	224.3	1,246,337	10,744
117	31.9	437.2	2.16	226.0	1,254,962	10,726
118	31.9	438.3	2.17	227.8	1,263,920	10,711
119	31.9	439.4	2.18	229.6	1,273,180	10,699
120	32.0	440.5	2.19	231.4	1,282,448	10,687
121	32.0	441.7	2.20	233.2	1,291,725	10,675
122	32.0	442.8	2.21	235.0	1,301,011	10,664
123	32.1	443.9	2.22	236.8	1,310,306	10,653
124	32.1	445.0	2.23	238.5	1,319,452	10,641
125	32.1	446.1	2.24	240.3	1,328,760	10,630
126	32.2	447.2	2.25	242.2	1,338,080	10,620
127	32.2	448.3	2.26	244.0	1,347,412	10,610
128	32.2	449.4	2.27	245.8	1,356,757	10,600

Table 7-7. Partial Load Performance at ISO Ambient Conditions (Cont)

Net Power per 200 kW module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (kW / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWh LHV)
129	32.3	450.5	2.28	247.6	1,366,114	10,590
130	32.3	451.6	2.29	249.4	1,375,483	10,581
131	32.3	452.7	2.30	251.3	1,384,866	10,571
132	32.3	453.8	2.31	253.1	1,394,263	10,563
133	32.4	454.9	2.32	255.0	1,403,673	10,554
134	32.4	456.0	2.33	256.8	1,412,997	10,545
135	32.4	457.1	2.34	258.6	1,422,226	10,535
136	32.5	458.3	2.35	260.4	1,431,464	10,525
137	32.5	459.4	2.35	262.2	1,440,713	10,516
138	32.5	460.6	2.36	264.0	1,449,971	10,507
139	32.5	461.8	2.37	265.8	1,459,240	10,498
140	32.6	462.9	2.38	267.6	1,468,174	10,487
141	32.6	464.1	2.39	269.5	1,477,702	10,480
142	32.6	465.3	2.40	271.4	1,487,248	10,474
143	32.6	466.5	2.41	273.3	1,496,813	10,467
144	32.6	467.7	2.42	275.2	1,506,395	10,461
145	32.7	468.9	2.43	277.1	1,515,997	10,455
146	32.7	470.1	2.43	279.0	1,525,618	10,449
147	32.7	471.3	2.44	280.9	1,535,259	10,444
148	32.7	472.4	2.45	282.9	1,544,919	10,439
149	32.7	473.6	2.46	284.8	1,554,601	10,434
150	32.7	474.8	2.47	286.8	1,564,303	10,429
151	32.8	476.0	2.48	288.7	1,574,027	10,424
152	32.8	477.2	2.49	290.7	1,583,773	10,420
153	32.8	478.4	2.50	292.7	1,593,542	10,415
154	32.8	479.6	2.51	294.6	1,603,333	10,411
155	32.8	480.8	2.52	296.6	1,613,148	10,407
156	32.8	482.0	2.53	298.6	1,622,986	10,404
157	32.8	483.2	2.53	300.6	1,632,849	10,400
158	32.8	484.4	2.54	302.7	1,642,738	10,397
159	32.8	485.6	2.55	304.7	1,652,651	10,394
160	32.8	486.8	2.56	306.7	1,662,591	10,391
161	32.9	488.0	2.57	308.8	1,672,558	10,389
162	32.9	489.1	2.58	310.8	1,682,552	10,386
163	32.9	490.3	2.59	312.9	1,692,574	10,384
164	32.9	491.5	2.60	314.9	1,702,625	10,382
165	32.9	492.7	2.61	317.0	1,712,704	10,380
166	32.9	494.0	2.62	319.2	1,722,814	10,378

Table 7-7. Partial Load Performance at ISO Ambient Conditions (Cont)

Net Power per 200 kW module (kW / N)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate per module (lbm/s / N)	Exhaust Energy Rate per module (kW / N LHV)	Fuel Flow Energy Rate per module (Btu/hr / N LHV)	Net Heat Rate (Btu/kWh LHV)
167	32.9	495.3	2.63	321.4	1,733,206	10,378
168	32.9	496.5	2.64	323.5	1,743,439	10,378
169	32.9	497.7	2.65	325.6	1,753,592	10,376
170	32.9	499.0	2.65	327.8	1,763,765	10,375
171	32.9	500.2	2.66	329.9	1,773,957	10,374
172	32.9	501.4	2.67	332.0	1,784,170	10,373
173	32.9	502.6	2.68	334.1	1,794,402	10,372
174	32.9	503.8	2.69	336.3	1,804,654	10,372
175	32.9	505.0	2.70	338.4	1,814,926	10,371
176	32.9	506.2	2.71	340.6	1,825,218	10,371
177	32.9	507.4	2.72	342.8	1,835,529	10,370
178	32.9	508.6	2.73	344.9	1,845,860	10,370
179	32.9	509.8	2.74	347.1	1,856,210	10,370
180	32.9	511.1	2.75	349.3	1,866,580	10,370
181	32.9	512.3	2.76	351.5	1,876,969	10,370
182	32.9	513.5	2.76	353.7	1,887,377	10,370
183	32.9	514.7	2.77	355.9	1,897,805	10,371
184	32.9	515.9	2.78	358.1	1,908,251	10,371
185	32.9	517.1	2.79	360.3	1,918,716	10,371
186	32.9	518.3	2.80	362.6	1,929,204	10,372
187	32.9	519.5	2.81	364.8	1,939,729	10,373
188	32.9	520.7	2.82	367.1	1,950,365	10,374
189	32.9	521.9	2.83	369.3	1,961,043	10,376
190	32.9	523.1	2.84	371.6	1,971,739	10,378
191	32.9	524.3	2.85	373.9	1,982,454	10,379
192	32.8	525.6	2.86	376.3	1,993,337	10,382
193	32.8	526.8	2.87	378.6	2,004,228	10,385
194	32.8	528.1	2.88	381.0	2,015,127	10,387
195	32.8	529.3	2.89	383.3	2,026,034	10,390
196	32.8	530.6	2.89	385.7	2,036,945	10,393
197	32.8	531.8	2.90	388.0	2,047,861	10,395
198	32.8	533.0	2.91	390.4	2,058,779	10,398
199	32.8	534.2	2.92	392.8	2,069,697	10,400
200	32.8	535.1	2.93	394.6	2,078,942	10,395

ISO partial load efficiency vs. net power for the 200 kW high pressure natural gas MicroTurbine power module is shown in Figure 7-3. These values are estimated from nominal performance at ISO conditions.

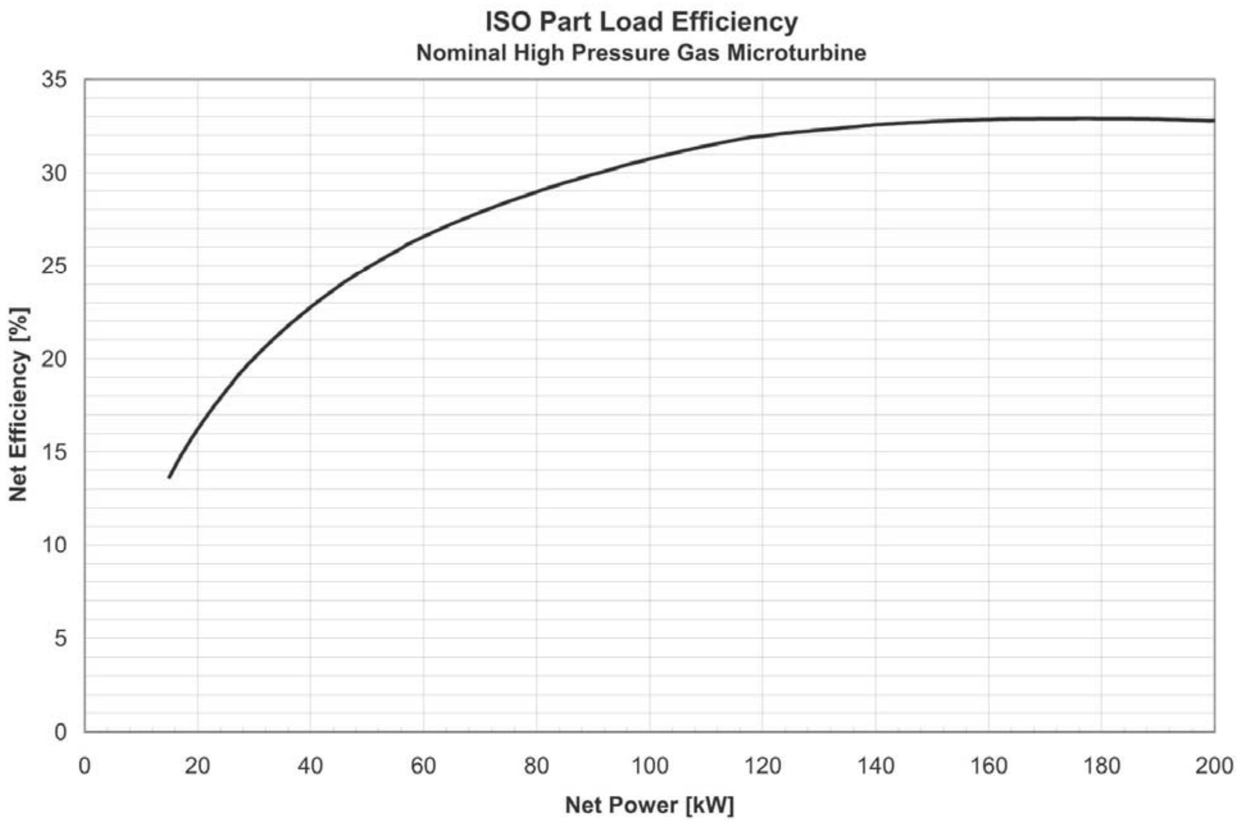


Figure 7-3. ISO Partial Load Efficiency Vs Net Power (Nominal)

ISO partial load efficiency vs. net power for the C1000 1 MW high pressure natural gas MicroTurbine power package operating in maximum efficiency mode is shown in Figure 7-4. Because this operational mode meets power demand by running as many units as possible at full power and only one unit at partial power, maximum efficiency is reached at a power output of only 200 kW, or 1/5 of the package maximum power output. This is a significant advantage over a similar single 1 MW turbine solution that would show a similar performance curve over the 1 MW to that shown in the individual 200 kW module above.

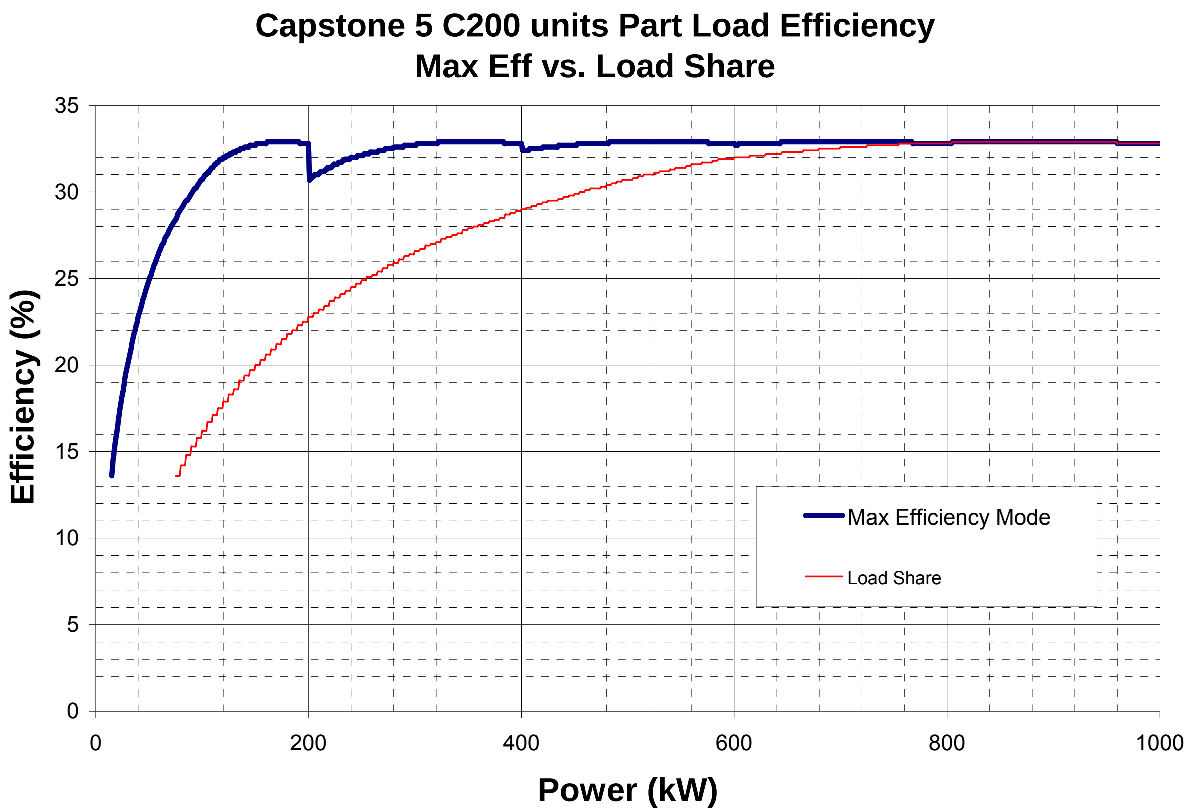


Figure 7-4. ISO Partial Load Efficiency Vs Net Power (Maximum Efficiency)

Example Calculations

Max Efficiency:

For example, using the part load table and a C1000 running at 500 kW (STP conditions) in max efficiency mode would have two modules running at 33% efficiency producing 400 kW and one module running at 100 kW at 30.7% efficiency. The overall efficiency is therefore [400kW*(33%) +100kW(30.7%)]/500kW = 32.5%.

Load Share:

If the system had been running in load share the efficiency would be 30.7%, because each of the five power modules would be running at 50% load.

CHAPTER 8: ELECTRICAL RATINGS

The purpose of this section is to define the electrical output ratings of the Capstone C600, C800 and C1000 MicroTurbine systems. The C600, C800 and C1000's can also be combined with C65, C200 and other C600's C800 or C1000 through the Advanced Power Server to achieve higher electrical outputs. For more information on connecting multiple Capstone MicroTurbines, please refer to the Advanced Power Server Installation Specification (480024). This information is intended for use in evaluating applications for a single Capstone C600, C800 or C1000 MicroTurbine.

Electrical ratings are dependent upon the operating mode selected; that is, Grid Connect or Stand Alone.

Grid Connect

Table 8-1 presents the Electrical Ratings for the Grid Connect configuration. Whenever an expression is listed, N equals the number of individual MicroTurbines within a MultiPac (N can be up to 20 if a C200 is the MultiPac Master, or more if the Capstone Advanced Power Server is acting as the MultiPac Master).

Table 8-1. Electrical Ratings: Grid Connect

Description	C600	C800	C1000
Grid Voltage Operating Range	352 to 528 VAC, (3-phase only)		
Output Voltage Connection	3 wire, L1, L2, and L3		
Maximum Grid Impedance	≤ 10% inductive (298 μH) ≤ 5% resistive (56 mOhms), Z_{base}= 1.12 ohms line-to-neutral		
Grid Voltage Harmonic Distortion	The grid must comply with IEEE 519. (Note 1).		
Grid Voltage Balance	Within ± 2% at full load		
Grid Voltage Phase Displacement	120 (± 1) degrees		
Grid Voltage Phase Rotation	Either clockwise or counter-clockwise. Auto synchronization. For Dual Mode applications, the grid voltage phase rotation must be L1, L2, L3 counter-clockwise		
Grid Inrush Current @ Disconnect Switch Closure	<45 Amps RMS	<60 Amps RMS	<75 Amps RMS

Table 8-1. Electrical Ratings: Grid Connect (Cont)

Description	C600	C800	C1000
Grid Frequency Acquisition Range	47 - 63 Hz. Auto synchronization. The MicroTurbine senses the grid waveform and synchronizes to its phases and frequency before an output connection is made.		
Real Power Output @ ISO (Note 2)	0 to 600 kW HP NG 0 to 570 kW LP NG 100 to 600 kW HP Landfill Gas 100 to 600 kW HP Digester Gas	0 to 800 kW HP NG 0 to 760 kW LP NG 100 to 800 kW HP Landfill Gas 100 to 800 kW HP Digester Gas	0 to 1000 kW HP NG 0 to 950 kW LP NG 100 to 1000 kW HP Landfill Gas 100 to 1000 kW HP Digester Gas
Apparent Power Output @ ISO	$kVA_{MT} = kW_{MT}$ (above)	$kVA_{MT} = kW_{MT}$ (above)	$kVA_{MT} = kW_{MT}$ (above)
Output Power Factor to Grid	± 0.985 displacement PF, for loads > 25% of rated load		
Output Power Slew Rate	±18 kW/second, for natural gas; ±6 kW/sec for Landfill/Digester Gas	±24 kW/second, for natural gas; ± 8 kW/sec for Landfill/Digester Gas	±30 kW/second, for natural gas; ±10 kW/sec for Landfill/Digester Gas
Maximum Output Current (Note 3)	690 Amps RMS @ 480 V LP NG 720 Amps RMS @ 480 V all others 825 Amps RMS @ 400 V LP NG 870 Amps RMS @ 400 V all others	920 Amps RMS @ 48 0V LP NG 960 Amps RMS @ 480 V all others 1100 Amps RMS @ 400 V LP NG 1160 Amps RMS @ 400 V all others	1150 Amps RMS @ 480 V LP NG 1200 Amps RMS @ 480 V all others 1375 Amps RMS @ 400 V LP NG 1450 Amps RMS @ 400 V all others
Output Current Harmonic Content	Complies with IEEE 519, UL1741: < 5% THD. See Figure 8-1.		
Output Current DC Content	<0.5% (4.2 Amps) DC (per UL 1741)	<0.5% (5.6 Amps) DC (per UL 1741)	<0.5% (7.0 Amps) DC (per UL 1741)
Grid Fault Current Contribution by MicroTurbine	1500 Amps RMS, maximum symmetrical and asymmetrical	2000 Amps RMS, maximum symmetrical and asymmetrical	2500 Amps RMS, maximum symmetrical and asymmetrical
Power Required @ Start Command (Note 4)	60 kW peak, 0.39 kW-Hr, 70 Seconds	80 kW peak, 0.52 kW-Hr, 70 Seconds	100 kW peak, 0.65 kW-Hr, 70 Seconds

Table 8-1. Electrical Ratings: Grid Connect (Cont)

Description	C600	C800	C1000
Cooldown Power (Note 5)	No net utility power 300 seconds		
Draw in Standby Power	0.90 kW	1.2 kW	1.5 kW
Grounding (Note 6)	Grid must be Neutral grounded.		
Surge Voltage Withstand	± 6 kV (ANSI 62.41)		
Short Circuit Rating	Per UL 508C, the MicroTurbine is not short circuit rated (Note 7)		

Notes:

(1) Total harmonic voltage must be less than 5% (13.9 VRMS line-to-neutral for a 480 V system). Also, the high frequency ripple voltage must be less than 2% (5.5 VRMS line-to-neutral for a 480 V system) at frequencies greater than 3 kHz.

(2) Refer Chapter 7: Performance for real power capability as a function of ambient temperature, elevation, and other site conditions.

(3) The maximum currents are limited by the real power capability of the MicroTurbine. Values listed are for full power at ISO conditions. Refer to Chapter 7: Performance for real power capability as a function of ambient temperature, elevation, and other site conditions.

(4) Start power required for full power start-up. Start-up can be staggered in order to reduce max start power required in Grid Connect Operations (where start power is pulled from the grid). Minimum start power using staggering is 20 kW with a 0.13 kW-hr 70 second draw.

(5) Any load connected to the auxiliary contactor is in addition to the motoring loads shown in order to keep the MicroTurbine in cooldown. Auxiliary contactor is not standard equipment on Grid Connect applications.

(6) Refer to Chapter 12: Installation for additional details.

(7) UL 1741 test-rated short circuit is 1500 A_{RMS}. For the C600, 2000 A_{RMS} for the C800, and 2500 A_{RMS} for the C1000.

Figure 8-1 presents the typical Total Harmonic Current as a function of load for one Capstone C600, C800, or C1000 MicroTurbine of a MultiPac in the Grid Connect mode.

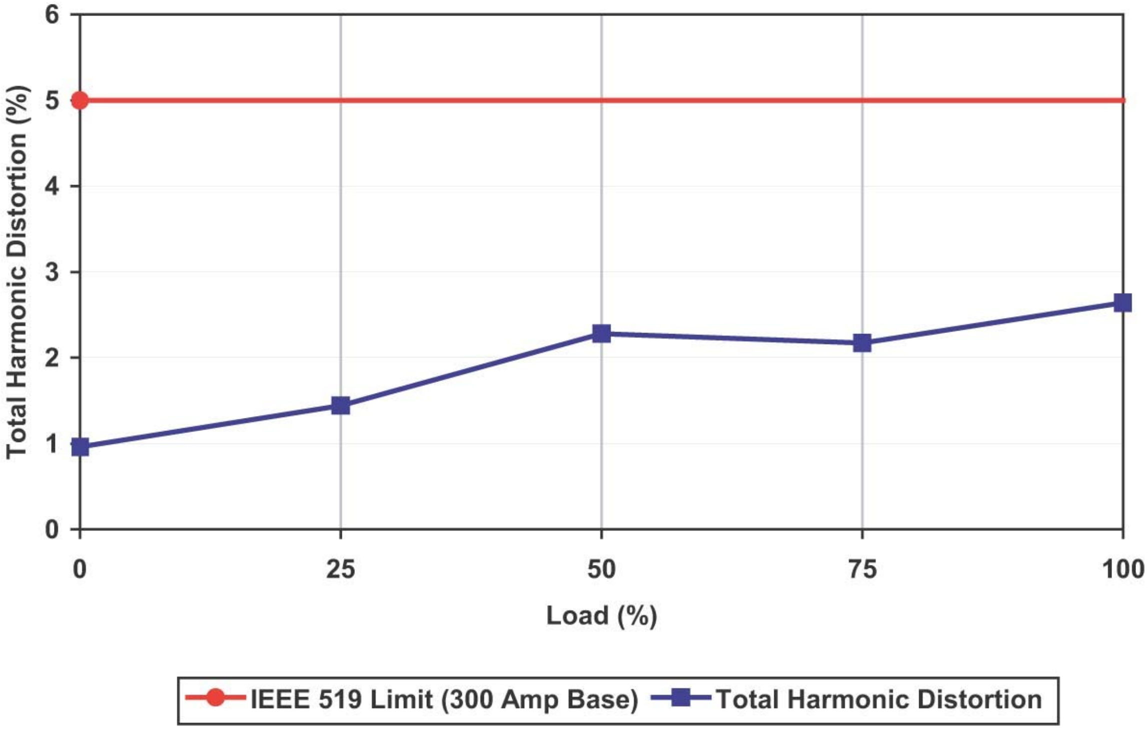


Figure 8-1. Typical Total Harmonic Current

Stand Alone

Table 8-2 presents the Electrical Ratings for the Stand Alone mode of operation. Whenever an expression is listed, N equals the number of individual MicroTurbines within a MultiPac (N can be up to 20 if a C200 is the MultiPac Master, or more if the Capstone Advanced Power Server is acting as the MultiPac Master).

Table 8-2. Electrical Ratings: Stand Alone

Description	C600	C800	C1000
Output Voltage Adjustment Range	150 to 480 VAC line-to-line (1 VAC adjustment resolution)		
Output Voltage Accuracy	± 2% of reading, (± 1% typical) line-to-neutral		
Output Voltage Stability, Time	± 1.5% per 40,000 hours		
Output Voltage Stability, Temperature	± 0.2% over 20 to 50 °C (ambient temperature)		
Output Voltage Configuration	3-Phase, 4 wire, L1, L2, L3, and N		
Real Power Output @ ISO (Note 1)	0 to 600 kW HP NG 0 to 570 kW LP NG	0 to 800 kW HP NG 0 to 760 kW LP NG	0 to 1000 kW HP NG 0 to 950 kW LP NG
Maximum Output kVA @ ISO (Note 2)	774 kVA @ 480 V 645 kVA @ 400 V	1032 kVA @ 480 V 860 kVA @ 400 V	1290 kVA @ 480 V 1075 kVA @ 400 V
Load Power Factor Range (Note 2)	0.8 lagging (inductive) to 0.8 leading (capacitive)		
Output Voltage Harmonic Distortion, with Linear Load	≤ 5% THD: complies with IEEE 519		
Output Voltage Harmonic Distortion, with CF load. Crest Factor (CF) = I_{PEAK} /I_{RMS}	< 8% THD, I_{PEAK} ≤ 2025 Amps 1.4 ≤ CF ≤ 3.0	< 8% THD, I_{PEAK} ≤ 2700 Amps 1.4 ≤ CF ≤ 3.0	< 8% THD, I_{PEAK} ≤ 3375 Amps 1.4 ≤ CF ≤ 3.0
Output DC Voltage Content	± 2.5 VDC line-to-neutral		
Output Voltage Step Load Regulation, load application or removal	< ± 20% of nominal voltage for any resistive step load ≤ 75% rated load		
Output Voltage Step Load Recovery Time	< 100 milliseconds to within ± 5% of nominal voltage for ≤ 75% rated load step		

Table 8-2. Electrical Ratings: Stand Alone (Cont)

Description	C600	C800	C1000
Output Voltage Phase Displacement	120 (± 1) degree @ balanced loads		
Output Voltage Phase Displacement Jitter	± 1 degree @ balanced loads		
Output Voltage Phase Rotation	L1, L2, L3 counter-clockwise		
Output Frequency Adjustment Range	45 - 65 Hz (0.1Hz adjustment resolution), ± 0.05% accuracy. For integer frequency settings, the accuracy is ± 0.005%.		
Output Frequency Regulation	0% change for any steady state load or transient load ≤ 75%		
Output Frequency Stability, Time	± 0.0005% per year		
Output Frequency Stability, Temperature	± 0.005%, -20 to +50 °C		
Maximum Output Current (Note 3)	930 Amps RMS	1240 Amps RMS	1550 Amps RMS
Output Load Crest Factor	2.18 maximum @ 930 Amps RMS CF=2025/I_{RMS} for loads < 930 Amps RMS	2.18 maximum @ Amps RMS = 1240 CF=2700/I_{RMS} for loads < 1240 Amps RMS	2.18 maximum @ Amps RMS = 1550 CF=3375/I_{RMS} for loads < 1550 Amps RMS
Output Instantaneous Load Current	2025 Amps peak, maximum	2700 Amps peak, maximum	3375 Amps peak, maximum
Overload Capacity (% of full rated power output)	150%, 10 seconds; 125%, 30 seconds; 110% 60 seconds (Note 4)		
Output Fault Current	1500 Amps RMS, maximum symmetrical and asymmetrical	2000 Amps RMS, maximum symmetrical and asymmetrical	2500 Amps RMS, maximum symmetrical and asymmetrical
Single Phase Loading (per individual MicroTurbine within the MultiPac)	240 kW line-to-neutral maximum steady state	320 kW line-to-neutral maximum steady state	400 kW line-to-neutral maximum steady state

Table 8-2. Electrical Ratings: Stand Alone (Cont)

Description	C600	C800	C1000
Maximum Load Unbalance among the 3 (Note 5)	240 kW	320 kW	400 kW
Surge Voltage Withstand	± 6 kV (ANSI 62.41)		
Grounding (Note 6)	Neutral must be solidly connected to earth ground in a single location.		
Motor Start, Across-the-line; Maximum inrush current (Note 7)	< 1425 Amps RMS	< 1900 Amps RMS	< 2375 Amps RMS
Motor Start, Ramp Voltage and Frequency (Note 7)	1425 Amps RMS	1900 Amps RMS	2375 Amps RMS

Notes:

(1) Refer to Chapter 7: Performance for real power capability as a function of ambient temperature, elevation, and other site conditions. Additional considerations for worst case operating environment, minimum tolerance band, and load safety margin need to be taken into account when designing a system for Stand Alone operation, so the maximum figures shown above should only be used as a reference.

(2) Values shown are limited by maximum current capability of the power electronics. For system design, total power factor for all connected loads should not be less than 0.8 (inductive or capacitive).

(3) The maximum steady state current is limited by the capability of the power electronics, and may be further restricted by the output capability of the MicroTurbine. Refer to Chapter 7: Performance for real and apparent power capability as a function of ambient temperature, elevation, and other site conditions.

(4) Values are for battery state of charge >70%. Note that overload capacity depends on the maximum real output power capability of the system. Refer to Chapter 7: Performance for real and apparent power capability as a function of ambient temperature, elevation, and other site conditions.

(5) A typical arrangement of unbalanced loads on a C1000 package could be 450kW, 50 kW and 50 kW. This results in a maximum load unbalance of 450kW-50kW=400 kW, which is in spec with the maximum unbalance limitation.

(6) Refer to Chapter 12: Installation for additional details.

(7) This current limit must not be exceeded at any time during acceleration to full motor speed.

Figure 8-2 presents the typical output voltage (Line-to-Line) Total Harmonic Distortion (THD) as a function of Linear Resistive Load for the Capstone C600, C800 and C1000 MicroTurbines.

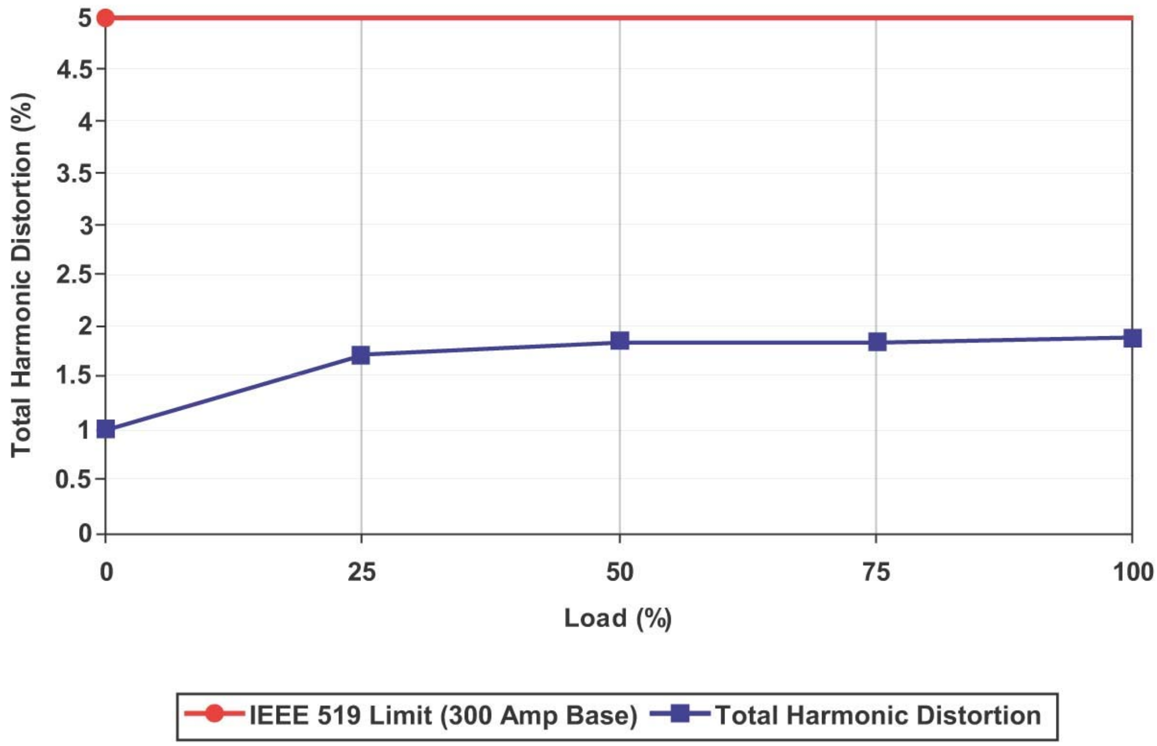


Figure 8-2. Typical Output Voltage Total Harmonic Distortion

Auxiliary Output

Introduction

This auxiliary contactor is a small AC power output connection that is available in the Power Connection Bay. It is standard on Stand-Alone (or Dual Mode systems) and is not provided on Grid Connect configurations. Its purpose is to supply AC output power of the same type as the primary output power to critical loads prior to the primary load being energized. This power can be used to enable control systems, pumps for water systems, heating systems, or any other systems that need to be active for a certain amount of time before and after the load is enabled. The reason this output is not included on Grid Connect models is because the Grid is usually capable of supplying any auxiliary loads when the primary output is not active.

Capacity

The auxiliary AC power output is not an independent power source from the primary AC power output, however it is an independently switched output. This means that the capacity of the system AC output equals the sum of the outputs of the main and auxiliary output. The auxiliary output is capable of delivering up to 30 kVA on the C600, 40 kVA on the C800 and 50 kVA on the C1000.

Timing

The auxiliary AC power output is energized once the system reaches the run state and stays energized until the shutdown, fault or restart states are reached. Additionally, a manual command and a discrete input control are available. These control the transition from the run state to the load state and allow the user the ability to control the timing between the auxiliary output contactor and the main output contactor closing. This timing control is also available in the form of a user settable timer for the routine shutdown transition from cooldown to the shutdown state. These various inputs and timers allow the user to customize the auxiliary output power for his particular site needs.

Measurement Accuracy

The displays of the output voltages, currents, frequencies, and power have typical accuracies and coefficients as presented in Table 8-3.

Table 8-3. Typical/Maximum Instrumentation Accuracy and Coefficients

Instrumentation Item	Accuracy and Coefficients (Typical/Maximum)
Current	±1.5% of Full Scale (typical) / ±3.0% (maximum)
Current Temperature Coefficient	±0.2% of Full Scale over –20 to +50 °C range
Voltage	±1.0% of Full Scale (typical) /±2.0% (maximum)
Voltage Temperature Coefficient	±0.2% of Full Scale over –20 to +50 °C range
Output Power	±2.5% of Full Scale (typical) /± 5.0%(maximum)
Output Power Temperature Coefficient	±0.4% of Full Scale over –20 to +50 °C range
Output Frequency	±0.05% of Reading (or Indication)
Output Frequency Temperature Coefficient	±0.005% of Reading over –20 to +50 °C range
Real Time Clock	±1 minute per month

CHAPTER 9: PROTECTIVE RELAY FUNCTIONS

Introduction

The Capstone MicroTurbine generator may be connected in parallel to a utility grid to power local Grid Connected loads. When installed in this fashion, power generated by the MicroTurbine is supplied to these loads only when the utility grid voltage is present. Utilities commonly require that protective relay devices be installed with generators connected to their grid. The primary purpose of these devices is to ensure that the local generator will not energize utility wires de-energized by the utility. Typically, these protective relay devices are dedicated relays or solid-state power analyzers that provide control signals to disconnecting devices. This document presents information for the protective relay functions incorporated into Capstone MicroTurbines.

The C600, C800 and C1000 MicroTurbine packages have built-in protective relay functions. Programmable settings for the protective relay functions are stored in nonvolatile memory within the MicroTurbine. As a result, any changes remain set even after an interruption in utility power. Resetting of these protective relays can only be done by a Capstone Authorized Service Provider. Contact Capstone Applications or Service if you feel that your application requires non-standard settings.

During utility grid voltage interruptions, the MicroTurbine senses the loss of utility voltage and disconnects from the grid and the local loads. When the grid voltage returns to within its specified limits, the MicroTurbine may be programmed to restart and supply power to the connected loads. Figure 9-1 shows the relationship between the MicroTurbine, local loads and the utility grid.

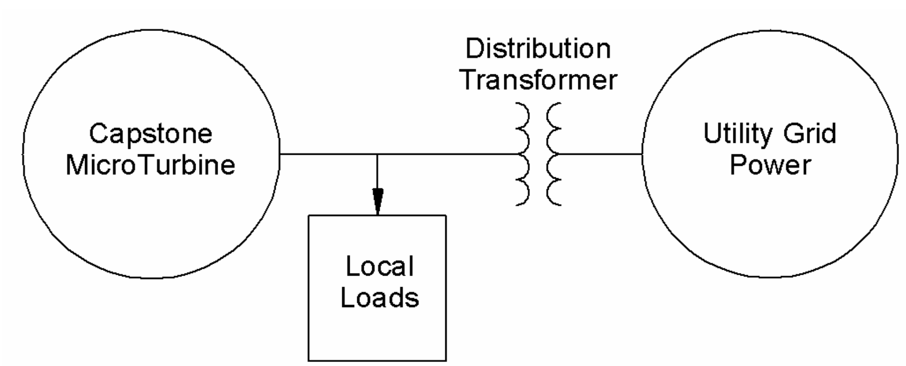


Figure 9-1. Grid Connect System Configuration

Protective Functions

The protective functions included in the C600, C800 and C1000 MicroTurbines are described in this section. Voltage sensing and signal processing are described in the System Overview section. The Protective Function designator numbers correspond to those published by IEEE[1].

NOTE	All protective function measurements and calculations are based on the Line-to-Neutral voltage values. However, for convenience, all protective function settings are entered as equivalent Line-to-Line voltage values.

When a protective function initiates a shutdown, the following occurs:

1. Output power flow ceases within one millisecond for at least four milliseconds.
2. The main power output contactor is opened within 100 milliseconds.
3. Fuel flow to the MicroTurbine stops, and
4. A warm shutdown begins, during which control power is supplied from the MicroTurbine generator as it slows down. The warmdown lasts 1 to 2 minutes before the rotor is stopped.

Under Voltage (Protective Function 27)

Primary Under Voltage Trip

The Primary Under Voltage is adjustable from 352 V_{L-L} up to the Over Voltage set point. (Initial factory setting = 422 V). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments. (Initial factory setting = 2.00 seconds)

The UL1741 requirement for this function is:

- The device should cease to energize the output within 2 seconds when any of the phase voltages is lower than 244 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each MicroTurbine is tested to verify that it meets the UL1741 requirement to initiate a Grid Fault Shutdown, if any phase-to-neutral voltage sags to less than 244 V_{L-N} for duration greater than 2.0 seconds.

The primary trip voltage set point may be adjusted upwards within the range indicated in Table 9-1 and still comply with UL1741.

The primary duration to trip may also be adjusted downwards as indicated in Table 9-1 and still comply with UL1741.

[1] IEEE C37.90-1989. IEEE Standard relays and Relay Systems Associated with Electric Power Apparatus. Institute of Electrical and Electronics Engineers, New York.

Fast Under Voltage Trip

The Fast Under Voltage is adjustable from 0 V_{L-L} up to the Under Voltage set point. (Initial factory setting = 240 V_{L-L}). The time period is adjustable from 0.03 to 1.00 second in 0.01 second increments. (Initial factory setting = 0.16 seconds)

The UL1741 requirement for this function is:

- The device should cease to energize the output within 0.16 seconds when any of the phase voltages is lower than 139 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each MicroTurbine is tested to verify that it meets the UL1741 requirement to cease power export to the grid within 160 ms if the phase-to-neutral voltage drops to 139 V_{L-N}.

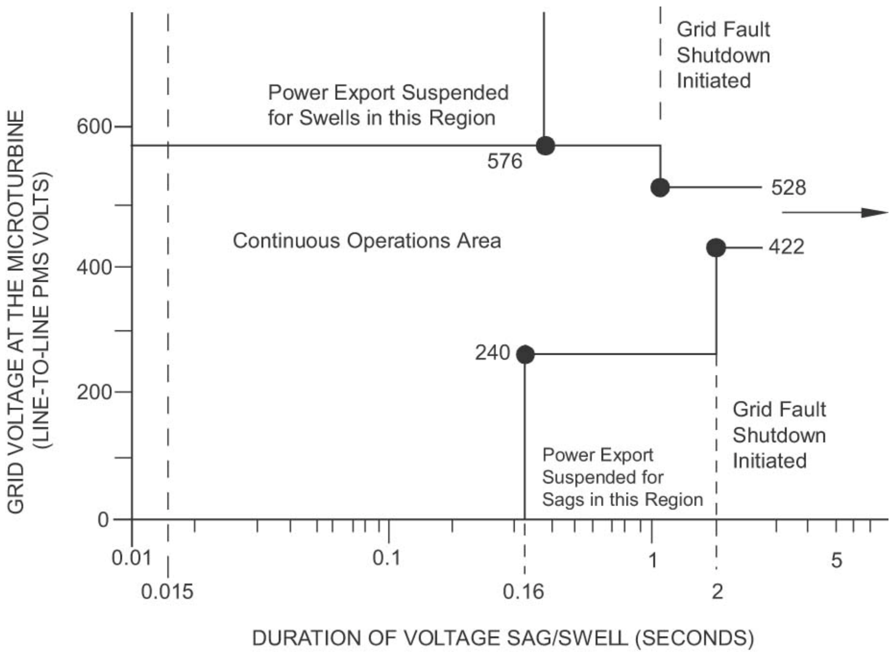
The Fast Under Voltage Trip level may be adjusted upwards as indicated in Table 9-1 and still comply with UL1741. The duration to the Fast Under Voltage Trip may also be adjusted downwards as indicated in Table 9-1 and still comply with UL1741.

The Under Voltage protective functions are illustrated in Figure 9-2. The under voltage trips are programmed into the MicroTurbine as phase-to-phase voltages.

Voltages indicated in Figure 9-2 are phase-to-phase voltages. However, the actual trip functions are based on phase-to-neutral voltages with equivalent trip levels.

Table 9-1. Under Voltage Protective Function Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Initial Factory Setting	RS-232 Command to read the settings
Under Voltage	If the voltage on any phase falls below this setting for greater than Under Voltage Time, the system will shut down.	352 to Over Voltage (L-L)	422	UNDVLT
Under Voltage Time	Establishes the time period allowed for any phase voltage to fall below the Under Voltage limit.	0.01 to 10 seconds	2.00	UVLTTM
Fast Under Voltage	The system will cease to export power to the grid within 1 msec if any phase voltage drops below this voltage for greater than Fast Under Voltage Time.	0 to Under Voltage (L-L)	240	FSTUVL
Fast Under Voltage Time	Establishes the time period allowed for any phase voltage to fall below the Fast Under Voltage limit.	0.03 to 1.00 seconds	0.16	UVFSTM



Note: Trip voltages and durations shown in Figure 9-2 are those entered into the C600, C800 or C1000 MicroTurbine prior to shipment. The Primary and Fast Over/Under Voltage trip levels and durations may be adjusted at installation as indicated in Table 9-1 and Table 9-2.

Figure 9-2. Grid Fault Shutdown Trip Limits for Over/Under Voltage Events

Over Voltage (Protective Function 59)

Primary Over Voltage Trip

The Primary Over Voltage is adjustable from 528 V_{L-L} down to the Under Voltage set point. (Initial factory setting = 528V). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments. (Initial factory setting = 1.00 seconds)

The UL1741 requirement for this function is:

- The device should cease to energize the output within 1 second when any of the phase voltages is higher than 305 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each MicroTurbine is tested to verify that it meets the UL1741 requirement to initiate a Grid Fault Shutdown if any phase voltage swells to greater than 305 VL-N for duration greater than 1.0 seconds. The primary trip voltage set point may be adjusted downwards within the range indicated in Table 9-2 and still comply with UL1741. The primary duration to trip may also be adjusted downwards as indicated in Table 9-2 and still comply with UL1741.

Fast Over Voltage Trip

The Fast Over Voltage is adjustable from the Over Voltage up to 634 V. (Initial factory setting = 576V). The time period is adjustable from 0.03 to 1.00 second in 0.01 second increments. (Initial factory setting = 0.16 seconds).

The UL1741 requirement for this function is:

- The device should cease to energize the output within 0.16 seconds when any of the phase voltages is higher than 333 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each MicroTurbine is tested to verify that it meets the UL1741 requirement to cease power export to the grid within 160 ms if any phase voltage swells to 333 V_{L-N}.

The Fast Over Voltage Trip level may be adjusted downwards as indicated in Table 9-2 and still comply with UL1741. The duration to Fast Over Voltage Trip may also be adjusted downwards as indicated in Table 9-2 and still comply with UL1741.

These Over Voltage protective functions are illustrated in Figure 9-2. The over voltage trips are programmed into the Power Controller as phase-to-phase voltages. Voltages indicated in Figure 9-2 are phase-to-phase voltages. However, the actual trip functions are based on phase-to-neutral voltages with equivalent trip levels.

Table 9-2. Over Voltage Protective Function Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Initial Factory Settings	RS-232 Command to read the settings
Over Voltage	If the voltage on any phase rises above this setting for greater than Over Voltage Time, the system will shut down.	Under Voltage to 528 V (L-L)	528	OVRVLT
Over Voltage Time	Establishes the time period allowed for any phase voltage to rise above the Over Voltage limit.	0.01 to 10.00 seconds	1.00	OVLTTM
Fast Over Voltage	The system will cease to export power to the grid within 1 msec if any phase voltage rises above this voltage for greater than Fast Over Voltage Time.	Over Voltage to 634 V (L-L)	576	FSTOVL
Fast Over Voltage Time	Establishes the time period allowed for any phase voltage to rise above the Fast Over Voltage limit.	0.03 to 1.00 seconds	0.16	OVFSTM

Over/Under Frequency (Protective Function 81 O/U)

The Over Frequency is adjustable from Under Frequency to 65 Hz; in 0.1 Hz increments (Initial factory setting = 60.5 Hz). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments (Initial factory setting = 0.16 seconds)

The UL1741 requirement for Over Frequency function is:

- The device should cease to energize the output within 0.16 seconds when the grid frequency is higher than 60.5 Hz.

The Under Frequency is adjustable from 45 Hz to Over Frequency, in 0.1 Hz increments. (Initial factory setting = 59.3 Hz). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments. (Initial factory setting = 0.16 seconds)

The UL1741 requirements for Under Frequency function for devices greater than 30kW rating are:

- The device should cease to energize the output within (adjustable 0.16 to 300 seconds) when the grid frequency is lower than (59.8 – 57.0 Hz adjustable set point).
- The device should cease to energize the output within 0.16 seconds when the grid frequency is lower than 57.0 Hz.

As shipped, each C600, C800 and C1000 MicroTurbine is tested to verify that it meets the UL1741 requirement to initiate a Grid Fault Shutdown, if the line frequency is greater than 60.5 Hz or is less than 59.3 Hz for a duration of 160 ms.

The Over Frequency trip limit may be adjusted downwards as indicated in Table 9-3 and still comply with UL1741.

The Under Frequency trip limit may be adjusted upwards as indicated in Table 9-3 and still comply with UL1741.

The duration to trip may also be adjusted downwards as indicated in Table 9-3 and still comply with UL1741.

Rate of Change of Frequency (Anti-Islanding Protective Function)

The C600, C800 and C1000 MicroTurbine packages contain integrated active anti-islanding protective functions. These include an excessive Rate of Change of Frequency protective function, which will cause a Grid Fault Shutdown. The anti-islanding protection is tested and verified as part of the UL1741 listing.

Over Current and Fault Current

In the Grid Connect mode, the total fault current capacity at the installation site is the sum of the fault current from the electric utility grid and that produced by all the on-site generators, including MicroTurbines. The rating of fault current interrupting devices at the site should be checked to ensure that they are capable of interrupting the total fault current available.

The electric utility grid operator will usually wish to be informed of the MicroTurbine fault current contribution in order to assess the impact of the additional fault current on the electric utility grid and customers connected to it. At most installation sites the addition of a Capstone MicroTurbine may not result in a significant increase in the total fault current. However, the potential impact of the increase in fault current should be assessed.

When operating in Grid Connect mode, C600, C800, or C1000 MicroTurbine operation is controlled to deliver current corresponding to the power delivery set point (but less than the maximum steady state current of the package as listed in the performance section).

C600, C800, and C1000 MicroTurbine packages do not include passive over current protection, but do provide extremely fast active current control. The MicroTurbine output acts as a current source, using the grid voltage as a reference for both magnitude and phase angle. Active current control ensures that the steady-state current will not exceed 930A per phase for the C600, 1240 A per phase for the C800 and 1150 A per phase for the C1000, regardless of the utility voltage.

Under transient or fault conditions, active current control and sub-cycle current interruption capability ensure that the RMS current in any half cycle does not exceed 1500 Arms (C600) 2000 Arms (C800) and 2500 Arms (C1000). For some severe transients, the inverter may shut down within 1 or 2 cycles due to excessive or unstable current. Even under these conditions, the RMS current in any half cycle will not exceed the limits previously mentioned.

For less severe transients, the active current control will maintain the current at a value not more than 930 Arms (C600) 1240 Arms (C800) and 1550 Arms (C1000). The MicroTurbine will continue to operate in this mode until some other protective function stops power flow. For example, the Fast Under Voltage protective function can be set to detect a reduced utility voltage and initiate a Grid-Fault Shutdown within 160 ms.

It is essential for safe operation and service that a circuit protective disconnect device (circuit breaker or fused disconnect) be installed between each C600, C800, or C1000 MicroTurbine package and the utility grid or protected loads. This protective device must be rated for the total fault current, and is intended to protect the MicroTurbine and associated power cables from fault current flowing back from the utility grid and/or other connected MicroTurbines. Local electric codes will almost always require this disconnect. The added functionality of this protective device is not considered here.

Reverse Power Flow (Protective Function 32)

If the C600, C800, or C1000 MicroTurbine output is greater than the local load demand, the excess power generated by the MicroTurbine will flow back to the grid. Return flow to the grid may be undesirable for two reasons: 1) The connected electric utility may not allow power to be exported to its grid, and therefore may require that generating equipment cease operation if this condition exists, or 2) The electric utility may not offer “net metering”, and therefore reverse power flow represents an economic loss to the MicroTurbine user.

The C600, C800, and C1000 MicroTurbine packages can be configured to provide reverse power flow protection in two different ways. Either method requires an external device be installed at the appropriate point in the distribution circuit to measure power flow. Utilities are normally most concerned about power flow back into their utility grid, and measure this flow at a Point of Common Coupling (or PCC) with onsite generating equipment. The preferred method is using a Modbus capable Power meter connected to the C600, C800 or C1000 controller.

The MicroTurbine controller will maintain the grid power import at the user's selected rate, varying the MicroTurbine power setting to handle the fluctuating site load. This feature can be coupled with time of use functions in the MicroTurbine controller allowing the user to avoid peak charges from the utility. Detailed requirements for this external equipment are described in Chapter 10: Communications – External Power Meter Inputs.

The reverse power protective functions of the C600, C800 and C1000 MicroTurbine systems may be enabled at installation, and can be configured to initiate a Normal Shutdown when reverse power flow is measured for a duration of 0 to 120 seconds. Note that an overall response time of zero (0) seconds cannot be realistically achieved. Normal Shutdown allows cooldown of the MicroTurbine to occur as opposed to a Grid Fault warmdown (shutdown) caused by the MicroTurbine's integrated voltage, frequency, and anti-islanding protection. During this cooldown, fuel is shut off but some power will still be output since the main contactor will remain closed and the heat energy stored in the recuperator must be dissipated.

Reverse Power Relay with Trip Signal

The use of a power meter, as mentioned above, is a convenient method to control the power set-point of the MicroTurbine package. In some cases, an additional reverse power trip will be required by local ordinances. Alternatively, a reverse power flow relay may be interfaced with the external fault inputs in the MicroTurbine controller to initiate a Grid Fault Shutdown when reverse power flow is detected. Typically the fault input would be configured to cause a fault severity level 4 shutdown (warmdown). This scheme will provide the quickest response to a reverse power situation, and will cause an operator to manually clear this severity level 4 fault before the MicroTurbine can be restarted. If required for your installation, contact Capstone Application Engineering to configure the reverse power trip connection.

NOTE	Some states have rigid requirements regarding proper reverse power flow to the utility during grid disturbances. In this case, the best approach is to use a utility-approved reverse power flow relay to provide a trip signal to the MicroTurbine. The relay trip signal output should interface with one of the MicroTurbine digital fault inputs and be software configured to fault severity level 4 (warmdown). When properly setup, the main output contactor on the C600, C800 and C1000 MicroTurbines will open to stop exporting power as soon as a trip signal from the reverse power protective relay is detected.

Shutdown

When one or more of the protective relay functions initiates a Grid Fault Shutdown, the MicroTurbine enters the warmdown state and the following events occur:

- The main output contactor is opened within 100 ms; output power flow ceases.
- Fuel flow to the turbogenerator stops.

During a warm shutdown, control power is supplied from the MicroTurbine generator as it slows down. The warmdown lasts 1-2 minutes before the rotor is stopped. The control software provides for an optional automatic Restart when grid voltage and frequency are within permitted limits for a programmable period of time (adjustable from 5 to 60 minutes).

When a Normal Shutdown is initiated by the Reverse Power Flow function, the MicroTurbine enters the cooldown state and the following sequential events occur:

- Fuel flow to the turbogenerator stops.
- A cooldown of the engine takes place lasting up to 10 minutes. During cooldown, the grid power is used to motor the engine.
- The main output contactor is opened upon completion of cooldown.

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CHAPTER 10: COMMUNICATIONS

Introduction

This section presents interconnection information for communications between any Capstone C1000 family MicroTurbine system controller and supervisory or associated peripheral equipment and/or other Capstone products such as the Advanced Power Server (APS) for creation of a Capstone MultiPac. All C1000 package communications connections are made through the C1000 controller and include the following:

- External Controls (Hardwire or Modbus)
  - Hardwire I/O
    - Start/Stop (Enable)
    - Local and Global E-Stop
    - Battery Wake
    - Fault Output
    - External Shutoff Valve
    - Dual Mode System Controller Interface
    - Optional Inputs and Outputs (Balance of Plant)
  - Modbus Slave for Control System Integration
    - SCADA, Station Control or Building Management System interface
  - Modbus RS-232 or RS-485 Master
    - External Power Meter input
    - Custom BOP equipment
- CRMS software with PC through Ethernet
- MultiPac connections
- Modems (Ethernet TCP/IP) for Remote connectivity

C1000 Controller Connections

Figure 10-1 shows the location of the controller on the C1000 packages. Figure 10-2 shows the connection locations within the controller. Connections for Hardwire I/O, Modbus, CRMS, MultiPac and remote communication are identified. Descriptions of each of these connections and their abilities are given below.

Figure 10-1. Controller Location on the C1000 Series

NOTE	All signal level input and output connections should be made using shielded twisted pair and run in separate conduit from power wiring to avoid interference.

NOTE	Maximum wire size for customer terminal connections is 18 AWG. Minimum recommended wire is 20 AWG.

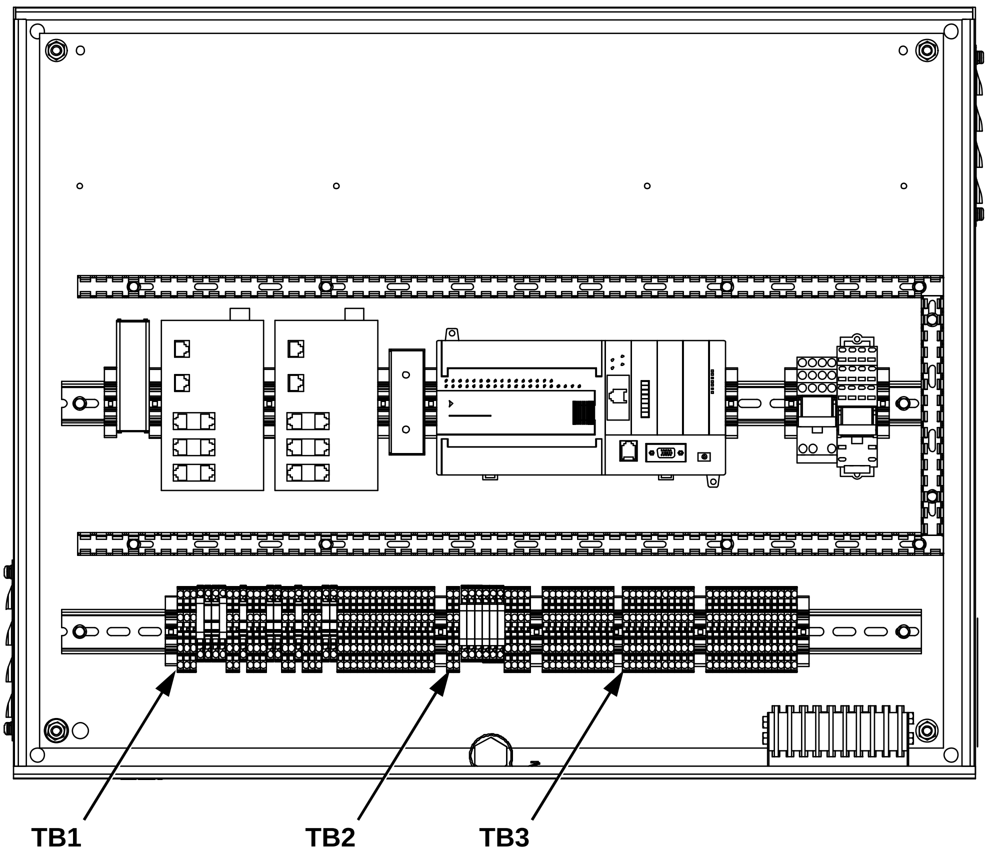


Figure 10-2. Connection Locations within the C1000 Controller

External Controls

The C1000 controller offers a number of options for external communication and control. While full control of the MicroTurbine system can be accomplished directly through the MicroTurbine controller's touch screen interface, connection to a Building Management System, Station Control System or other SCADA system is available with Modbus and may be desired for system integration with existing control systems. Hardwired signals are also available for safety and control functions as well as interface with external equipment. In addition, custom control configurations may require additional I/O that will be accessed through the C1000 controller. Refer to Appendix B: C1000 Controller Schematic for all terminal connections in the C1000 controller.

Start/Stop (Enable) Inputs

The C1000 MicroTurbine package can be started and stopped through commands issued at the C1000 controller or from remote control systems. The Start/Stop signal, sometimes called the "Start Enable" signal, is a configurable hardwire control system interlock that provides a permissive for a C1000 start command when true. If this start permissive is not present through hardwire, the unit will not start and if the start permissive is removed during operation, the unit will shutdown. The proper connections must be made in the C1000 controller for the desired start/stop control function, and the User/Remote options must be selected from the External Input Dispatch function using CRMS software.

- User - System is controlled locally through the C1000 controller or by using CRMS (no hardwired start input connection required)
- Remote – Start/Stop input connection wired to remote system.
- Configure hardware connections in the C1000 controller for the required Start Input mode as indicated in Table 10-1.

Table 10-1. Start/Stop Input Connection Details

Start/Stop Input Mode	Terminal Block	Pin Numbers
User	---	No connection
Remote or Combinations of User and Remote	TB3	Pins 15 and 16

Refer to Table 10-7 for additional terminal connection information. Note that closing an external contact will initiate a start, and opening this same contact will stop the MicroTurbine.

Local and Global Emergency Stop

Two Emergency Stop (E-Stop) inputs are available for each C1000 package in the C1000 controller (see Figure 10-2). The E-Stop inputs are identified as Local and Global E-Stops. These inputs are simple contact closures intended for dry contact circuits, where "closed" means normal operation and open initiates an E-Stop.

- Local E-Stop is used on a single MicroTurbine system. When activated, it will stop the C1000 package only.
- Global E-Stop is used on MultiPac Configurations. It will be connected to one MicroTurbine in the MultiPac, but will stop all MicroTurbine systems in the MultiPac.

NOTE	If no external E-Stop device is installed, the E-Stop terminals in the C1000 controller must be jumpered.

CAUTION	Emergency stops increase stress on system components. Repeated use of the Emergency Stop feature will result in damage to the MicroTurbine. For most applications, use this only in emergency situations. In all non-critical stops it is recommend that the Start/Stop enable input be used in order to ensure a more controlled shutdown and minimize wear on MicroTurbine components.

Refer to Table 10-2 for E-Stop connections in the C1000 controller.

Table 10-2. E-Stop Connection Details

E-Stop	Terminal Block	Pin Numbers
Global	TB1	10 and 11
Local	TB1	8 and 9

Battery Wake-Up

Dual Mode C1000 family MicroTurbines will automatically go into sleep mode if they are not connected to a live utility grid for a preset time. This is to protect their batteries from being discharged, which would result in the loss of unit black starting ability. The Battery Wake-Up feature is provided on the C1000 controller to wake a system that is in sleep mode so that a normal start sequence can begin. This action is sometimes referred to as Battery Start.

Local starting of a Dual Mode system that is in sleep mode requires the use of the Battery Wake button in the C1000 controller front panel. The Battery Wake command can also be issued remotely with a momentary contact closure across the battery start contacts on TB1-48 and TB1-49. Refer to Table 10-4 below for additional terminal information.

Fault Output

One fault summary output is provided as a discrete hardwired signal in the C1000 controller. The output is accessed through terminal block TB3 pins 25 and 26.

The fault output summary is triggered in situations where the C600, C800 or C1000 package has experience some fault that results in all 200 kW power modules being unavailable. This situation can be due to a MicroTurbine fault, heat, or gas detection.

This output can be used for remote indication of the fault status.

External Gas Shutoff

In some installations local codes or other requirements may require the use of an external fuel gas shutoff valve at the C1000 MicroTurbine package inlet. The C1000 controller includes a normally open discrete output for interface to an external fuel gas shutoff valve.

The output of the External Gas Shutoff signal follows that of the Fault Output described above plus the E-Stop. In any case where a fault summary is received, this output will command a fail-closed gas shutoff valve to close by interrupting its enabling current.

Dual Mode System Controller Interface

As described in the Operating Modes section, the C1000 MicroTurbine system requires both hardware and software inputs to tell it which operating mode to be in. If the system is to be operated only in Grid Connect or Stand Alone modes, a hardwired jumper should be connected as shown in Table 10-1. If the system is to be used in dual mode operation, these connections should be controlled externally (such as by using the Capstone Dual Mode System Controller accessory). Configure jumpers or use external contacts for the required operating mode as described in Table 10-3.

Table 10-3. Operating Mode Connection Details

Operating Mode	TB3 Connections	Power Connect Software Setting
Grid Connect Only	Jumper pins 17 and 18	Grid Connect
Stand Alone Only	Jumper pins 19 and 20	Stand Alone
Dual Mode	Use External contact closures instead of permanent jumpers	Dual Mode

The integration of the Dual Mode System Controller (DMSC) will require the wiring of power and control signals between the C1000 controller and the DMSC. Refer to the Dual Mode System Controller Technical Reference (410071) and Table 10-4 for the terminal block connection details.

Table 10-4. C1000 Controller and DMSC Terminal Block Connections

Terminal Block	Terminal Numbers	Signal
TB3	17 and 18	GC Enable
TB3	19 and 20	SA Enable
TB3	15 and 16	Start/Stop

Optional Inputs and Outputs (Balance of Plant)

The C1000 controller includes a PLC that can handle additional application specific input and output points or customer Balance of Plant needs. During site design, the end user determines what additional equipment should be monitored and controlled by the C1000 controller. Typical equipment includes a digital power meter for load following capability (see section on power meters below), utility interconnect protective relays if necessary, ICHP water pump controls, integrated chiller status signals, process heating controller commands/status signals, etc. Once this is determined and defined on the appropriate Capstone form, Capstone's Applications group writes the custom PLC code to configure the C1000 controller to function as required for the custom application. Ask your distributor about Custom PLC programming for the C1000 controller.

Once configured, these I/O values can be passed through Modbus for SCADA or BMS monitoring or used as part of the C1000 MicroTurbine control logic.

The PLC can support the following optional I/O items:

- Optional I/O Modules (the PLC has two card slots to support any two of the following):
  - 4 x 24-volt digital inputs/ 3 x 240 VAC relay contacts optional module (must be placed in slot #3 on the PLC if there is only one discrete input module).
  - 4 in / 2 out Analog current optional module (4 – 20 mA).
  - 4 in / 2 out Analog voltage optional module (0 – 10 V).
  - 4 Thermocouple inputs optional module.
  - 4 RTD inputs optional module.
  - 4 Analog current input optional module (4 – 20 mA).
  - 4 Analog voltage input optional module (0 – 10 V).
- 128 Modbus RS-485 Slave Device Registers (see section on power meter integration below).
- 50 APS controller data values and/or settings.
- 10 Registers for simple math calculations based on any of the registers above.

Modbus Slave for Control System Integration

For applications where a separate supervisory control system, SCADA system or Building Management System controller is used, the C1000 controller can operate as a slave device on an RS-485 communications bus, using standard Modbus RS-485 protocol. For these applications, the C1000 controller has a configurable Modbus slave memory map that allows the user to determine what information is needed from the C1000 controller. This is a configurable setting that is set up during the system commissioning as defined by the site designer for control and data monitoring of the MicroTurbines or groups of MicroTurbines.

Refer to Appendix A: C1000 Modbus Register List for information on available registers. This list is provided to give the user an idea of the type of information available as a standard through Modbus. In most cases the standard configuration is sufficient for complete integration with a station, building or SCADA system. Because this list may change from time to time it is important to request a project specific list before this reference is used for programming purposes. Refer to the C1000 User's Manual (400024) for information on manipulating and configuring Modbus communication.

External Power Meter Inputs

The Electrical Load Following and Reverse Power Flow functions require the installation of an optional 3-phase power meter at the utility Point of Common Coupling or the location at which reverse power flow protection is desired. The C1000 controller is designed to accept signals from a Modbus slave power meter using RS-485 wired to the PLC. Refer to Figure 10-3 and Table 10-5 for power meter connections.

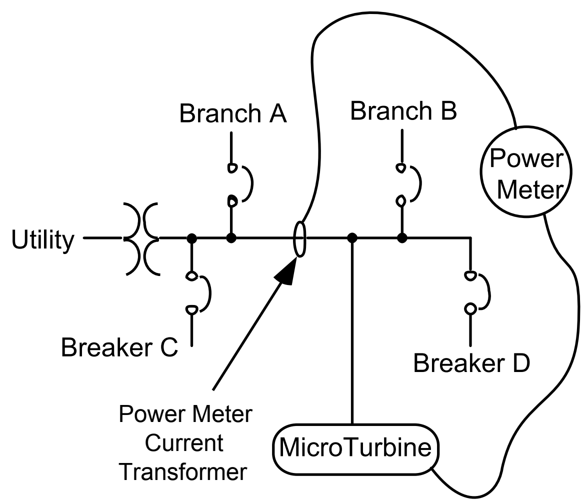


Figure 10-3. Power Meter installation

The external power meter should be placed in a location to produce the demand signal. Loads on the load side of the power meter current transformer location will produce demand signals, load on the utility side will not. The demand on the MicroTurbine will be calculated as the difference between the Utility Power setting entered during this setup and the actual load measured by the power meter.

For example, in Figure 10-3, loads on Branches B and D only will determine the MicroTurbine power output demand. Branch A or C loads have no effect. The MicroTurbine may be connected at breaker location, B or D (or an entirely different circuit). Power output demand will still be determined by the flow through the power meter current transformers.

Table 10-5. Modbus Power Meter Wiring Pins to C1000 Controller PLC

Terminal Block	Terminal Numbers	Parameter
TB1	56	Modbus Data (-)
TB1	57	Modbus Data (+)
TB1	58	Shield

DC Power Outputs

The C1000 controller includes a UPS supply of 24 volt power that can be used by equipment such as the Dual Mode System Controller (DMSC), a modem, VPN Gateway, external power meter, or Modbus repeater. On Dual mode systems this power is available only when the controller is awake. Because of the limited capacity of the UPS battery used in the controller and the importance of maintaining sufficient charge to allow a black start start-up of the MicroTurbine units, it is recommend that no more than 10 watts be used for external 24 volt power equipment from this source. If higher currents draws are required it is recommend that custom PLC logic be used to configure a PLC output via relay to energize the external circuit only when grid power is available or the MicroTurbines are exporting power.

Refer to Table 10-6 for the 24 VDC output connections in the C1000 controller.

Table 10-6. 24 Volt DC Power Source (10 Watt Max)

Terminal Block	Terminal Numbers	Parameter
TB1	3	24 VDC (+)
TB1	4	0 V

Note:

(1) Connections made to these terminals MUST be isolated from ground/chassis. They may not be connected in parallel with other MicroTurbine input and/or power supply terminals.

MultiPac Connections

The types of signal connections on the C1000 controller for MultiPac communication are as follows:

1) Ethernet via the Ethernet surge protector in the C1000 controller to the APS.
2) RS-485 MultiPac cable from C1000 controller terminals TB1-42 thru TB1-47 to other MultiPac C1000s, or C200 and C65 MicroTurbines.
3) For Dual Mode systems, a battery wake-up signal from the APS to the C1000 controller terminals TB1-50 and TB1-51.
4) An optional E-Stop signal from the APS to the C1000 controller terminals TB1-10 and TB1-11.

The interconnection diagram in Figure 10-4 shows these two types of signal interconnections, along with the required signal terminations. The case is shown for a MultiPac of two C1000's and one C200. This covers all possible scenarios, since a MultiPac with C65s is identical with C200s.

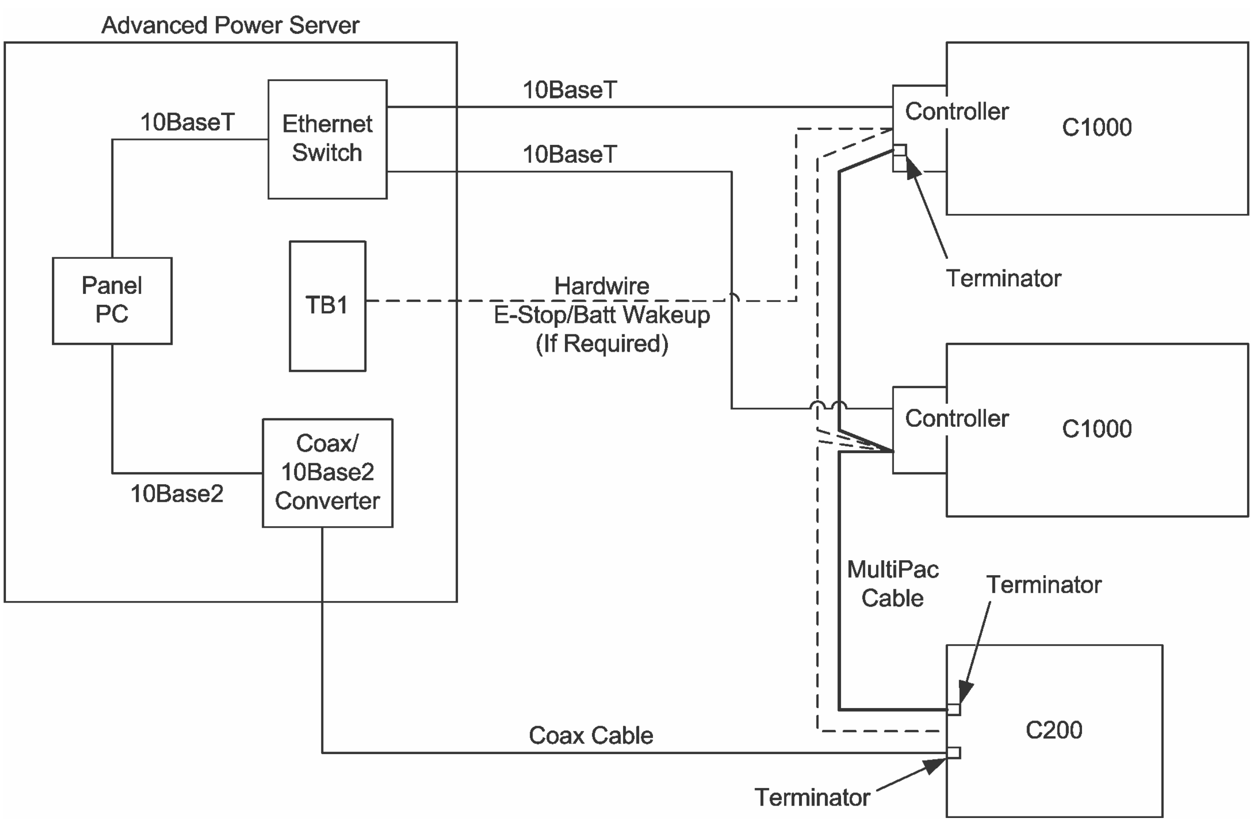


Figure 10-4. MultiPac Signal Interconnections

Ethernet

Ethernet signals are used for command and control. Commands (i.e. start/stop, power demand) are input to the APS. The APS then sends resulting commands to each MicroTurbine in the MultiPac. The APS routinely queries MicroTurbines for operational and fault data.

NOTE	The maximum total 10Base-T cable length is 100 meters. Fiber optics will be required for longer runs.

MultiPac Cable

The MultiPac cable is a RS-485 cable that transfers inverter synchronizing signals between MicroTurbines. The MultiPac cable is not needed if operating in Grid Connect mode. The MultiPac cable transmits RS-485 Bus A protocol and Bus B protocol serial communication from one MicroTurbine to another. One turbine serves as an Inverter Master, passing voltage and frequency signals to all other turbines for synchronization.

NOTE	The maximum total RS-485 cable length is 1000 meters. A repeater will be required for longer runs in Dual Mode Applications.

Signal Terminations

End-of-line signal terminators MUST be present on the initial and final connection for both Ethernet coax and MultiPac cable connections. If terminations are not present, electrical ringing may be present, and the signal may be severely degraded or interrupted.

Cable Connection Details

Refer to Table 10-7 for reference information about RS-485 MultiPac, and APS battery wake-up and E-Stop connections.

Table 10-7. C600, C800 and C1000 Connectors

Terminal	Signal	Parameter
TB1-42 or TB1-45	Serial Communication	RS-485, Bus A Protocol (Note 1)
TB1-43 or TB1-46	Serial Communication	RS-485, Bus B Protocol
TB1-44 or TB1-47	Chassis Ground	Chassis Ground
TB1-50	APS Battery Wake-Up	+24 VDC @ 15 milliamps per MicroTurbine (Refer to Table 10-8)
TB1-51	APS Battery Wake-Up Return	30 milliamps per MicroTurbine @ 0 VDC
TB1-10	Global E-Stop	Normal Operation: N*85 milliamps. E-Stop: (+) 24 VDC (Refer to Table 10-8)
TB1-11	E-Stop Return	Normal Operation: N*85 milliamps. E-Stop: 0 VDC

Notes:

(1) Capstone-provided terminators must be installed at the ends of the RS-485 cable within the C1000 controller. The maximum number of nodes is 32, and the maximum RS-485 cable length is 1000 meters. Each MicroTurbine has 1.93 meters of internal cable length, which must be included in the total length considerations. Repeaters may be added whenever the maximum cable lengths or the maximum number of nodes are exceeded.

Table 10-8 provides application guidance on limitations of each of the control functions. Please contact Capstone if your application is outside of these limits.

Table 10-8. Twisted Wire Pair Limits

Wire Pair	Limits
RS-485 Serial Communications	1000 m total cable length (Note 1)
Battery Wake-Up	Maximum 20 MicroTurbines
Global E-Stop	Maximum 20 MicroTurbines and 100 meter total cable length

Notes:

(1) Capstone-provided terminators must be installed at the ends of the RS-485 cable within the C1000 controller. The maximum number of nodes is 32, and the maximum RS-485 cable length is 1000 meters. Each MicroTurbine has 1.93 meters of internal cable length, which must be included in the total length considerations. Repeaters may be added whenever the maximum cable lengths or the maximum number of nodes are exceeded.

CRMS-APS with Ethernet

Overview

The C1000 controller provides a Local Ethernet port for connection of a PC running CRMS-APS. This connection provides full visibility of the C1000 controller to the PC's CRMS session as well as full CRMS functionality for each 200 kW power module within the C1000 package. In addition to the local CRMS Ethernet connection, CRMS can also run through a Remote LAN connection or a Remote WAN (trough an Ethernet modem or VPN router). Direct connection of CRMS to the 200 kW power modules is not required for full CRMS functionality.

Connections to Third-Party Modems

The following paragraphs present connection details between the MicroTurbine and the third-party modems.

Communications Cable

The C1000 controller has an Ethernet LAN connection that provides an access point for the PC running CRMS. Likewise, this connection can be used to connect the C1000 controller to a LAN for operation of CRMS from any computer on the LAN. The Capstone network will have to be mapped in the router on the customer's LAN. A sample routing command is shown in Appendix A.

Modem and MicroTurbine Settings

The MicroTurbine port speed setting must be set to the same speed as the modem.

Some telemetry modems have different modes for data packet transmission. For the MicroTurbine to communicate properly, the transmitted data packets should never be split. For example, some modems have a mode (for example DOX mode), by which the data packets are kept together during transmission.

The modem used for communication with the MicroTurbine should be TCP/IP capable and have Ethernet port connections instead of a serial connection. This would allow a single modem to be used to access multiple MicroTurbines at the same site.

Wireless Modems

For remote MicroTurbine installations where no landline telephone service is available, a radio or cellular modem is highly recommended for monitoring and troubleshooting the MicroTurbine system. Several third-party cellular and radio modems have been successfully used with the Capstone MicroTurbines.

Resources for Wireless Modems

A list of recommended modem vendors and model numbers that may be suitable for installation at your location is presented below. Contact your local cellular telephone service companies for a list of cell modems with coverage in your area. For telemetry and radio modems, be aware of local and FCC regulations, as well as permits required for using air radio frequencies. The usage of some radio frequencies may require special licenses.

NOTE	Cellular modem models and brands vary greatly depending on the service offered in your area. Contact your local telephone companies for the service and models available.

Cellular Modems:

Manufacturer: Airlink
Website: www.airlink.com
Model: Airlink Raven II CDPD

Manufacturer: Motorola
Website: www.motorola.com
Model: 781GWTY164Y

Radio/Telemetry Modems:

Manufacturer: Data Radio
Website: www.dataradio.com
Model: Integra H

Manufacturer: Locus Inc.
Website: www.locusinc.com
Model: OS2400–485

User Password Levels

The C1000 controller can be operated in two modes: monitoring mode or control mode. When power is applied to the C1000 controller, the user and maintenance ports boot up in the base level, which allows the monitoring mode of operation. In the monitoring mode, no password is required to perform basic data acquisition commands and monitor the status of the C1000 system.

Control mode operation is available at the protected level, which requires password authorization to access. Each system has a unique, user-defined password that can be changed at any time. The factory-set password for first time access to the protected level is **0123456789**. It is recommended that you change the protected-level password for your system after using the initial, factory-set password. Once access to the protected level is attained, system control functions include starting and stopping, and programming of setpoints.

Customer and Ancillary Connection Wiring Summary

Table 10-9 provides a summary of customer and ancillary equipment external connections in the C1000 controller.

Table 10-9. Customer and Ancillary I/O Connections

Pin	Signal	Ratings
TB1-48	Wake-up signal if asleep (Switch)	+24 VDC source on contact closure
TB1-49	Wake-up signal if asleep (Switch) Return	-24 VDC return
TB1-10	Global E-Stop	70 mA contact rating for external switch
TB1-11	Global E-Stop Return	24 VDC sink
TB1-8	Local E-Stop	70 mA contact rating for external switch
TB1-9	Local E-Stop Return	24 VDC sink
TB1-3	DMSC 24 VDC Power (Output)	24 VDC 5 A (+)
TB1-4	DMSC 24 VDC Power Return	24 VDC 5 A (-)
TB3-15/16	Remote Start/Stop	Dry contact rated for 24 VDC 2 A
TB3-17/18	GC Enable (Grid Connect mode)	Dry contact rated for 24 VDC 2 A
TB3-19/20	SA Enable (Stand Alone mode)	Dry contact rated for 24 VDC 2 A
TB1-56	Modbus Slave A (Data-)	5 VDC RS-485 (PLC Data–)
TB1-57	Modbus Slave A (Data+)	5 VDC RS-485 (PLC Data+)
TB1-58	Modbus Slave A Shield	Shield GND in Panel
TB1-59	Modbus Master (Data-)	5 VDC RS-485 (Panel PC Data–)
TB1-60	Modbus Master (Data+)	5 VDC RS-485 (Panel PC Data+)
TB1-61	Modbus Master Shield	Shield GND in Panel

CHAPTER 11: MAINTENANCE

Capstone MicroTurbine Systems require little maintenance due to their robust design and use of air bearings. The use of air bearings, coupled with the fact that the MicroTurbine system does not incorporate a mechanical transmission, means that no lubricants or coolants need to be periodically disposed of or replaced.

Scheduled Maintenance

Refer to the Capstone Standard Maintenance Schedule Work Instruction (440000) for details on the recommended service items and times.

Battery Life

Battery life expectancy is dependent on several factors, but is most strongly dependent on operating temperature and the number of times the batteries are used to start the C600, C800 or C1000 MicroTurbine stand-alone systems. Operating temperatures are a function of the ambient temperature as well as the temperature rise due to repeated load cycling.

Battery life can therefore be estimated by multiplying the base life times temperature derating and start derating factors. Provided the battery is maintained by appropriate equalization charges, a base life of 26,282 hours should be used.

Expected life = Base Life x Temperature Derating x Starts Derating

Example:

Ambient temperature = 30 °C

C1000 with 200 kW load transient every 200 seconds

200 Starts per Year

Step 1: Base Operating Hours.

Start with a base number of operating hours for 3 years or 26,280 hours.

Step 2: Find the Operating Temperature of the Battery.

Using Figure 11-1, find the temperature increase over ambient for the given transient load size and the transient interval. The transients are shown here in per power module load transients. If a C1000 is used with a 200 kW transient load, the transient per module will be 200kW/5 = 40 kW. The Temperature increase over ambient can be read from the y-axis on this figure. Add this value to the ambient temperature to get the battery temperature during operation; in this example 30 + 5 = 35 °C.

Step 3: Find the Temperature Derating of the Battery.

Using Figure 11-2, find the battery temperature (30 + 5 = 35 °C) on the x-axis and read the derating from the y-axis; in this example, 0.50. This number is multiplied by the number of hours from Step 1.

Step 4: Find the Number of Starts Derating.

Approximate the number of starts that the MicroTurbine will have in a one-year period. Find this number on the x-axis on Figure 11-3 and read the corresponding value from the y-axis. This number is multiplied by the number of hours in Step 2. In this example, 200 starts per year corresponds to 0.98.

Step 5: Calculate Lifetime of Battery.

Multiply the number of hours from Step 1 by the derating factors from Step 3 and 4. The result is the number of operating hours expected to battery end of life.

Expected life = 26,282 hours x 0.50 x 0.98 = 12,878 operating hours

Note that the expected battery life should not be more than 20,000 operating hours or 3 years elapsed time for scheduled maintenance purposes, even if the MicroTurbine is used for standby or in a Dual Mode application.

Figure 11-1 provides an estimate of battery temperature rise as a function of size and frequency of repetitive load transients.

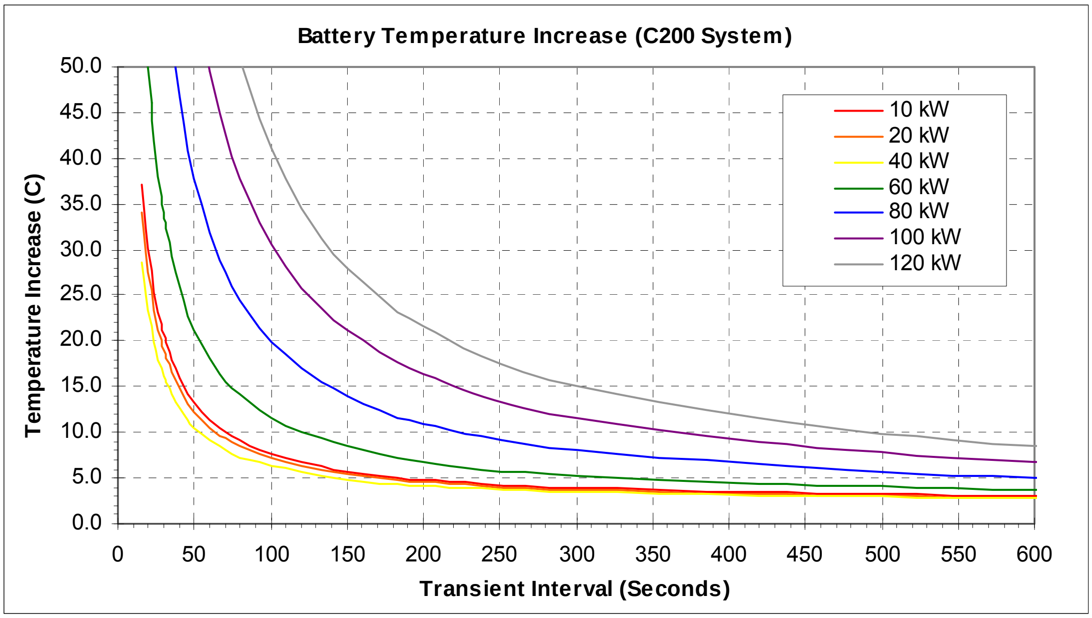


Figure 11-1. Battery Temperature Increase due to Load Transients (per power module)

Figure 11-2 shows the appropriate derating factor for a given ambient temperature. The battery temperature during cycling should be estimated by adding the value obtained from the appropriate temperature increase chart, and the ambient temperature.

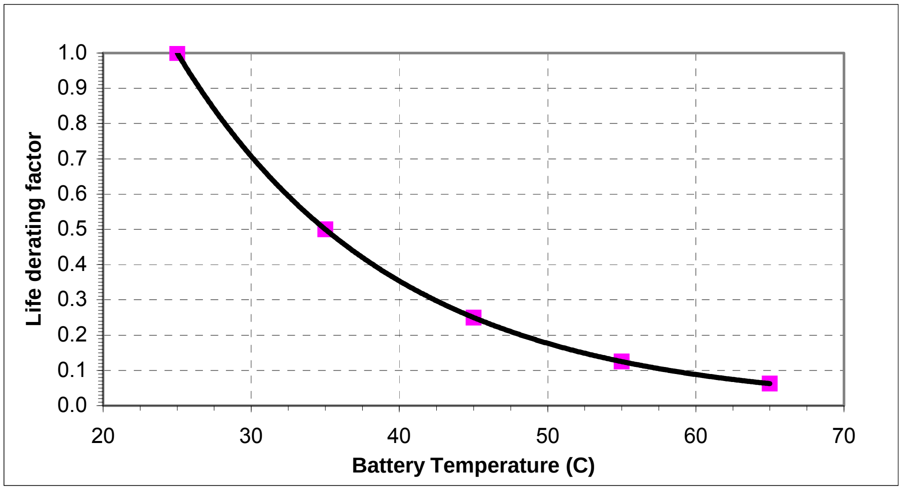


Figure 11-2. Temperature Derating for Battery Life

Figure 11-3 shows the appropriate derating factor for the number of starts per year. To find the derating, find the number of starts in one year on the x-axis, and follow the curve up to the line. The derating can be read from the y-axis.

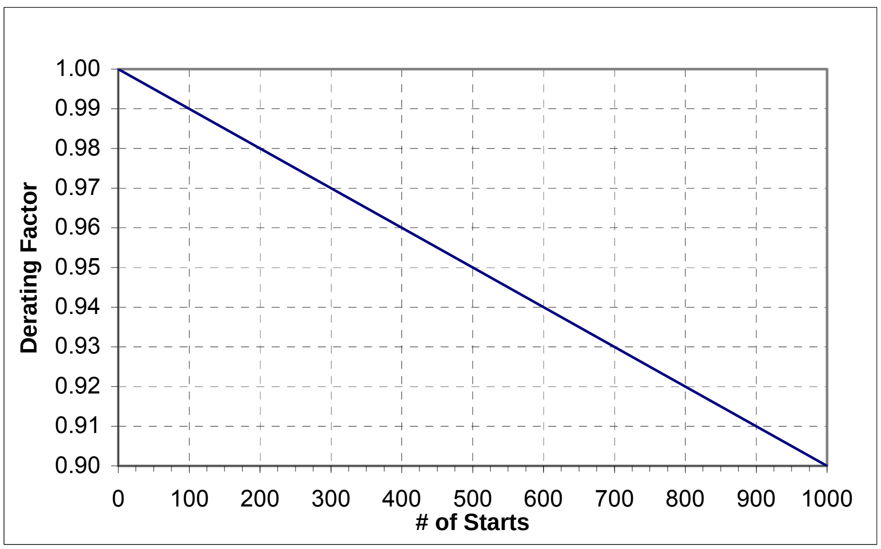


Figure 11-3. Derating for Number of Starts per Year

CHAPTER 12: INSTALLATION

Introduction

This section explains basic package installation and describes some example applications of the C1000 Series MicroTurbine including external equipment in a variety of power applications, as well as a subsection on the electric utility interconnection process. This section is provided for reference only and provides some best practices for specific applications. Capstone is able to provide application specific support for your application. Refer to the latest revision of the C1000 Series O&I Drawing (524341) should be referenced with regard to any dimensional clearance data. Refer to Figure 12-1 for the fuel and power connections on the C1000 Series MicroTurbine

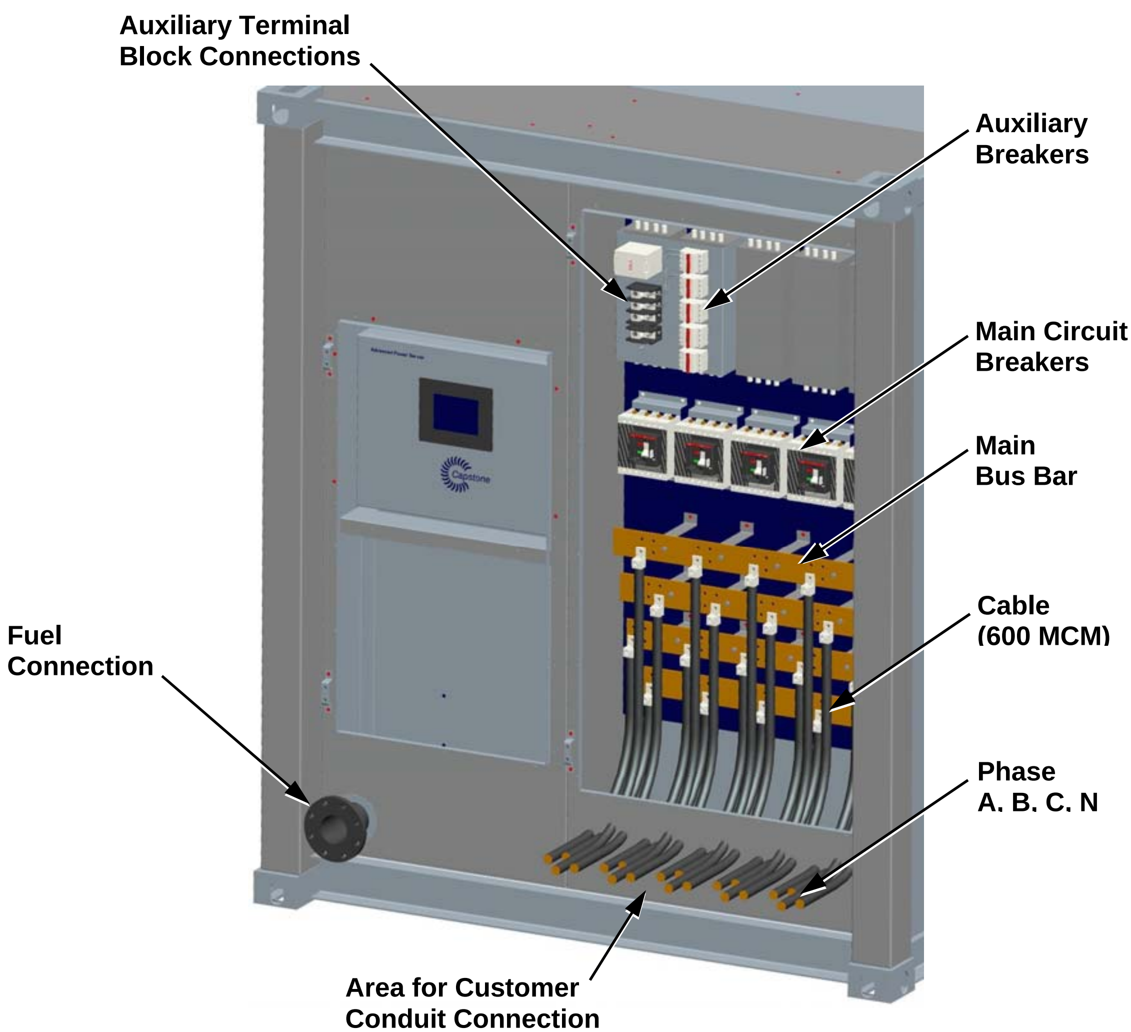


Figure 12-1. Fuel and Power Connections (Dual Mode Configuration Shown)

Fuel Connection

All C1000 series MicroTurbine power packages using gaseous fuel use one 4 inch 150# ANSI RF flanged fuel connection.

Power Connection

Main power connections are made using sets of 600 MCM cable (three phases plus neutral). The use of multiple 600 MCM cables allows bend radius to be reduced to 14 inches. Main power connection can be made through side entry on the end of the package or through the bottom of the package, with appropriate field work to the package.

MicroTurbine	Main Power Connection
C600	3 sets 600 MCM
C800	4 sets 600 MCM
C1000	5 or 4 sets 600 MCM

Dual Mode systems include an additional auxiliary contactor power output. This power output is available before the main contactor power and can be used to power external application specific equipment. More information on this source is available in previous sections of this document. Aux Power connection is made using sets of 2 AWG (66 MCM) cable sets (three phase plus neutral).

MicroTurbine	Aux Power Connection
C600	3 sets 66 MCM (2 AWG)
C800	4 sets 66 MCM (2 AWG)
C1000	5 sets 66 MCM (2 AWG)

Shipping and Handling

The C1000 Series MicroTurbine is contained in a 30-foot ISO-style enclosure. The enclosure includes corner castings for lifting and tie-down, and fork lift pockets for lifting (requires the use of an oversize forklift). While the container is not an ISO standard, it does have the same dimensions as a CAT megawatt power package.

The most economical method for overseas shipping is the use of a 40-foot flat rack for shipping, rail and truck transport. This allows a properly protected C1000 to be treated much like an ISO container for much of the required handling. Due to the C1000 package dimensions (30 x 8 x 9 feet) the unit is not ISO compliant in both width and height for standard flat rack shipping. This should be brought to the attention of the freight forwarder at the time of quotation.

Foundation

The C1000 Series MicroTurbine packages require a level, solid foundation for field installation. Because the C1000 packages are contained within an ISO-style enclosure, no additional environmental protection will be required for most applications.

The C1000 Series enclosure can be installed and supported from the unit's four corner castings. The small offset from the enclosure bottom and these corner castings allows for water runoff drainage, preventing possible enclosure corrosion due to standing water. Refer to C1000 Series O&I Drawing (524341) for system weights for pad design.

Service Clearances

Sufficient service area clearances are required for serving of the C1000 Series MicroTurbine packages. Reference the C1000 Series O&I Drawing (524341) for minimum required service areas. These minimum requirements are base on the minimum possible service areas for removal of internal package components. Your installation may require greater service areas depending on the other equipment expected to be used during maintenance (for instance a truck or forklift for engine or component removal). These service area requirements can not be reduced.

Example Applications

Grid Connect Operation - Connection to a Utility System

Grid Connect operation mostly entails generating power in peak-shaving or base-load applications, displacing grid-supplied electricity when generation on-site can be done more economically, and in many cases more efficiently and with fewer emissions than electricity generated at a central plant.

Inverter-based technology allows MicroTurbines to use grid voltages as a reference for power production as a current source. Seamless operation with the grid, with unity power factor and power ramping capability, helps customers meet load profile requirements as well as relieves strain on the grid distribution system while reducing grid heat losses.

Capstone MicroTurbines are designed to safely produce power in parallel with an electric utility. Relay protection functions required for safe interconnection are built-in MicroTurbine features, accommodating flexibility for a range of voltage and frequency settings. Field adjustable settings accommodate safe fault clearance at specific multiphase fault conditions.

Figure 12-2 depicts a typical Grid Connect installation.

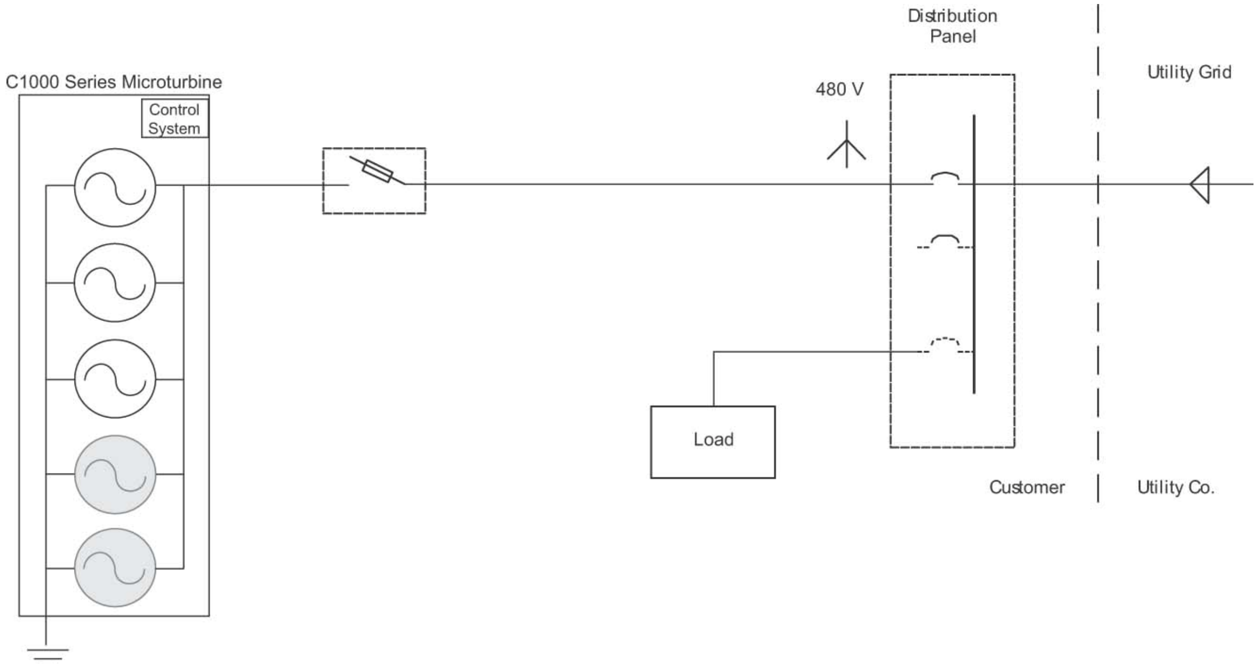


Figure 12-2. Grid Connect Operation

Grid Connect operation may be enhanced using a power meter to provide power flow signals to the MicroTurbine.

In grid-parallel applications with variable electric loads, economics and/or utility restrictions may require that no power, or limited power, be exported to the utility. This requirement can be met using an external power meter, as shown in Figure 12-3.

Using a power meter's signals, a MicroTurbine can dynamically adjust its output power level to ensure that limited or zero power flows back to the utility. This application is called 'Load Following'. For details on setting up a power meter, refer to the Chapter 10: Communications - External Power Meter Inputs in this document.

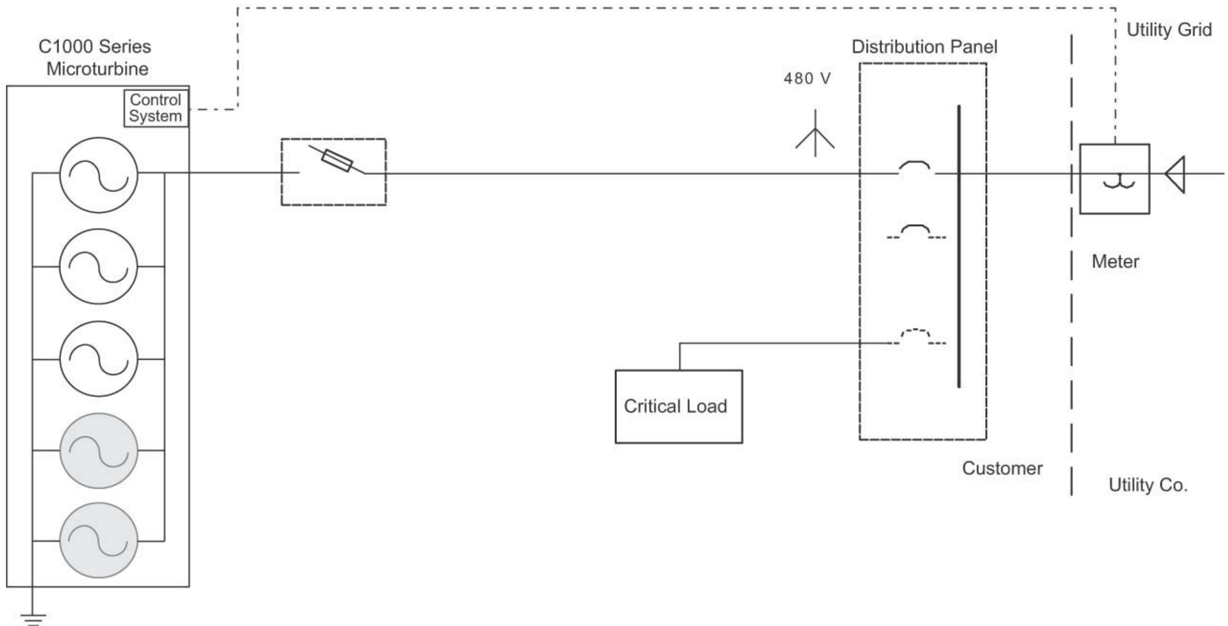


Figure 12-3. Grid Connect, Load-Following Operation Using a Power Meter

Stand Alone (Remote) Operation – MicroTurbine as Sole Power Source

In Stand Alone mode, the MicroTurbine solely supports the load, providing required voltage, active and reactive power. Stand Alone capable MicroTurbines are equipped with a battery and battery controllers. The battery is used for both starting the MicroTurbine and supplying transient energy to connected loads.

Figure 12-4 shows a typical remote power diagram.

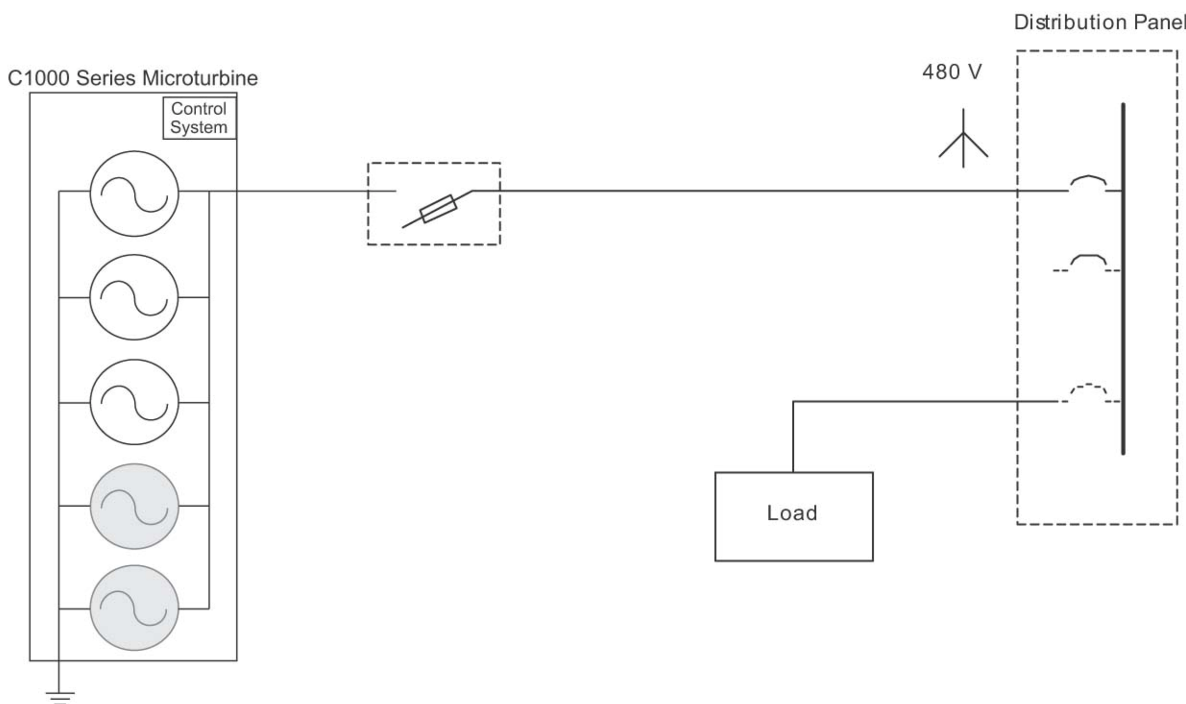


Figure 12-4. Stand Alone (Remote) Operation

Dual Mode – MicroTurbine is Both Grid Connect and Standby

The term 'Dual Mode' refers to a MicroTurbine's ability to operate both in parallel with a commercial utility or isolated from the utility in Stand Alone mode. Manual transfer between these modes of operation may be accomplished with a manual switch. Automatic or manual transfer may also be accomplished using a Capstone Dual Mode System Controller (DMSC). In cases where the load cannot tolerate any interruption, a UPS is used upstream of the critical load.

Figure 12-5 depicts a typical dual-mode configuration.

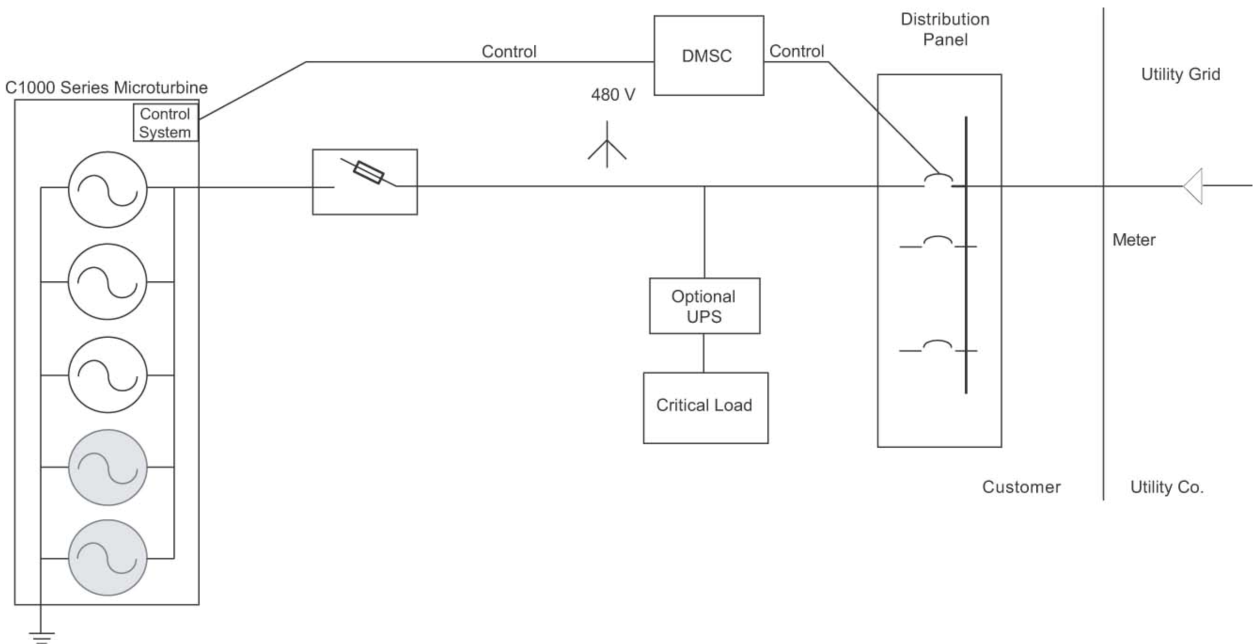


Figure 12-5. Dual Mode Operation

The DMSC serves as an inter tie disconnect between the grid and the load. Any load downstream of the DMSC is termed the critical or protected load.

The critical load may be supplied from either:

- Commercial Utility (power company grid or line power)
- Both utility and MicroTurbine operating in parallel (Grid Connect, or GC)
- Or the MicroTurbine by itself (Stand Alone, or SA).

The transfer is initiated by:

- An undervoltage relay, built into the DMSC, in case of the grid outage, or
- Manually, by operator via the DMSC's front panel.

In Grid Connect mode, when a grid outage occurs, the DMSC circuitry senses the outage and opens a motorized switch or circuit breaker, isolating the MicroTurbine and load from the utility. The MicroTurbine may be configured to transition automatically to Stand Alone mode and resume power production, upon isolation from the utility.

The load experiences a power outage of a maximum of 10 seconds during such a transition. When the grid returns to normal operation, the DMSC will signal the MicroTurbine to resume Grid Connect operation and will close the utility line circuit, supplying power to the load. When utility power is restored, the loads will return to the grid within five (5) seconds. The MicroTurbine may be operating in a "Hot Standby" mode for up to 30 minutes, to be sure the utility voltage remains stable before reconnecting in Grid Connect mode.

Reliability Operation, Isolated – MicroTurbine as Grid or Prime Power Source

MicroTurbine operation may be completely isolated from the utility by means of an Automatic Transfer Switch (ATS). Several operating modes are possible using an ATS, each mode having different performance characteristics. In all cases, the schematic is generally the same.

The differences lie in whether the grid or MicroTurbine is configured as primary power, and how the MicroTurbine is configured to operate. In cases where the load cannot tolerate any interruption, a UPS is used upstream of the critical load.

Figure 12-6 depicts a typical configuration using an ATS.

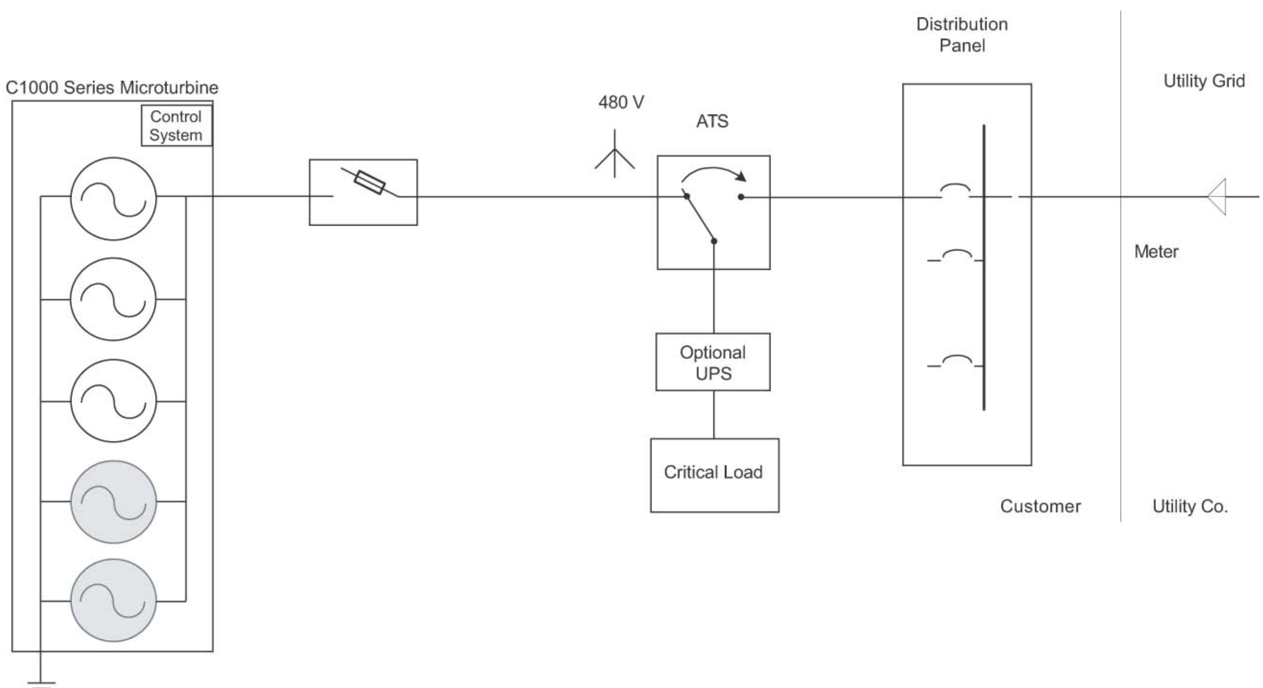


Figure 12-6. Isolated Operation

Table 12-1 outlines various operating modes possible using both Dual Mode System Controllers and transfer switches, with performance characteristics.

Table 12-1. Mode/Configuration Performance Comparison

Mode of Operation vs. Interruption	External Equipment	Prime to Backup Delay	Backup to Prime Delay
MicroTurbine as Prime* or Standby, plus UPS. MT can operate in Grid Connect mode as prime, peaking or standby; grid failure initiates MT shutdown/restart, batteries ride through event.	Battery UPS	None	None
MT Grid Connect and Stand Alone* MT runs grid connected, shuts down and restarts in Stand Alone mode upon grid failure.	DMSC**	<10 sec***	<5 sec
MT Stand Alone Prime, Grid as Backup* MT provides prime power, with ATS switching to utility only if MT goes offline.	ATS	<5 sec	<5 sec
Grid Prime, MT Standby MT runs only when utility fails, in Stand Alone mode	DMSC** or ATS	<6 min***	<5 sec
Grid Prime, MT idling Stand-Alone MT idles in isolated Stand Alone mode (load state), providing power to the load only during grid failure	ATS	<5 sec**	<5 sec

*Co-generation (exhaust utilization for heating, drying, absorption chilling) is possible with continuous/extended operation.

**Capstone auto-switching Dual Mode System Controller allows better load matching than an ATS, as MT power in excess of the critical load can flow to non-critical loads upstream of the DMSC. ATS does not allow Grid Connect operation, or the utilization of excess MT power. However, ATS transfer times are faster, and a utility interconnection agreement may not be required.

***Assume MicroTurbine internal battery state of charge >60%.

Single Phase Applications

In applications where the connected load is single phase, there are several ways to convert the MicroTurbine's three-phase output to single-phase. Note that this is only applicable to Stand Alone applications.

120-240 Volt

The most useful and recommended way is called a Zig-Zag connection (see Figure 12-7), utilizing three single-phase transformer banks, and is shown below for several applications. The 480/120-240 VAC topology produces a center-tapped 240 VAC voltage source. Two sources of 120 VAC power are available on either side of the center tap. Note that the 120 VAC power sources are 180° apart. The 240 VAC source may be loaded to 66% of the MicroTurbine kW capacity, or each 120 VAC source may be loaded to 33% individually.

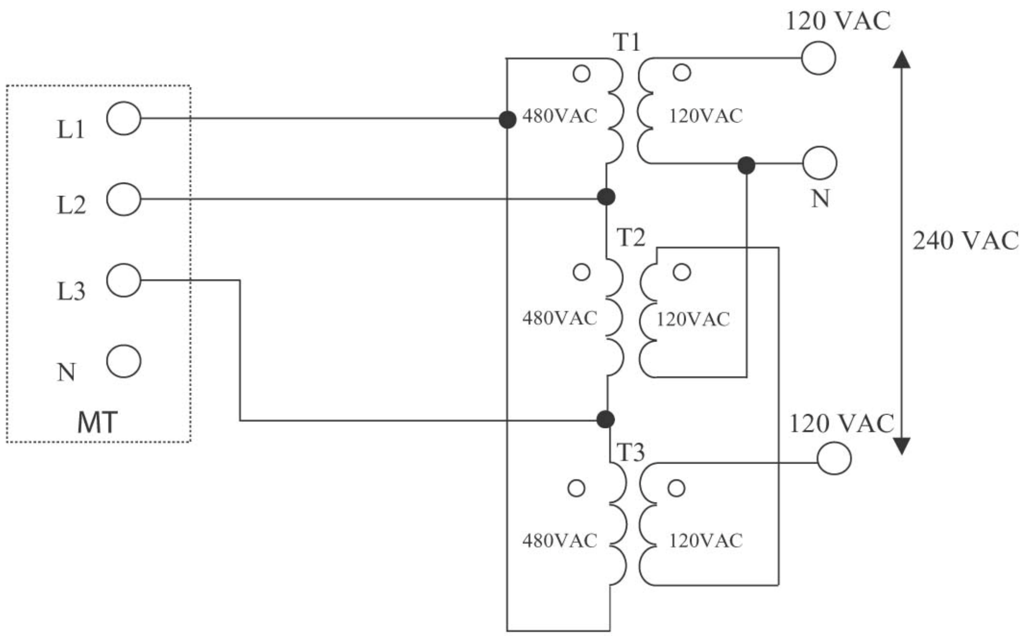


Figure 12-7. Zig-Zag Connection

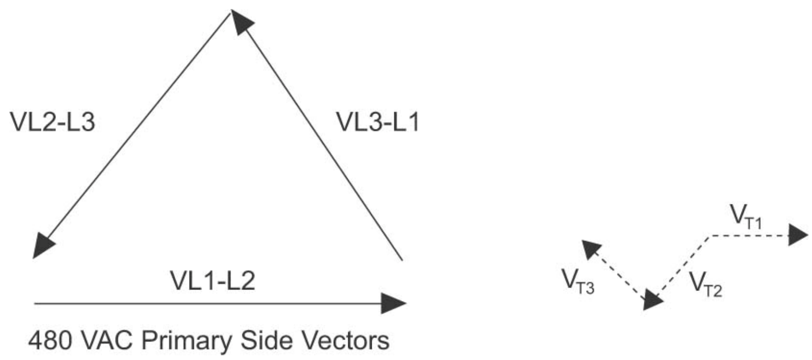


Figure 12-8. Zig-Zag Vector Diagram

Each transformer in the zig-zag connection must be rated for 67 kVA. The utilization factor for the set of 3 transformers is 66.7%. The utilization factors of the individual transformers are:

UF_{T1} = 100%

UF_{T2} = 50%

UF_{T3} = 50%

Example for a C600: In a typical application 396 kW of power may be delivered to a 120/240 VAC load. The individual loadings are:

MicroTurbine Power = 396 kW

Total transformer capacity: 396 x 1.2 = 475 kVA

T1 = 160 kVA

T2 = 160 kVA

T3 = 160 kVA

Phase L1-L2 Power = 160 kW

Phase L1-L2 VA= 160 kVA

Phase L2-L3 and L3-L1 Power = 160 kW

Phase L2-L3 and L3-L1 VA = 160 kVA

120-208 Volt

Two single transformer banks, 480/120 VAC can be connected to produce 120 VAC and 208 VAC, as follows.

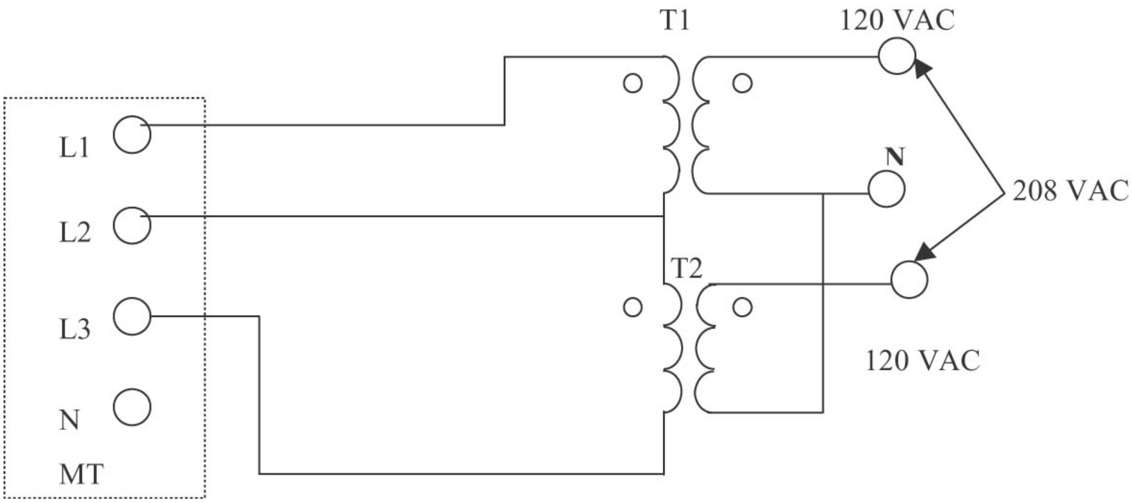


Figure 12-9. 120/208 VAC Single-Phase Diagram

In all above cases, it is only possible to draw 2/3 of the MicroTurbine's maximum power rating.

NOTE	Relay protection functions in the MicroTurbine do not allow grid-parallel operations in any of the above single phase applications.

Full Power

When a single-phase load can be distributed between three mutually exclusive electric panels, full power output can be achieved.

The following example illustrates single-phase configuration for full power utilization, with the output circuits, at 67 kW each. This example is essentially a three-phase application, where the phases are isolated. Phases can be up to 100% imbalanced.

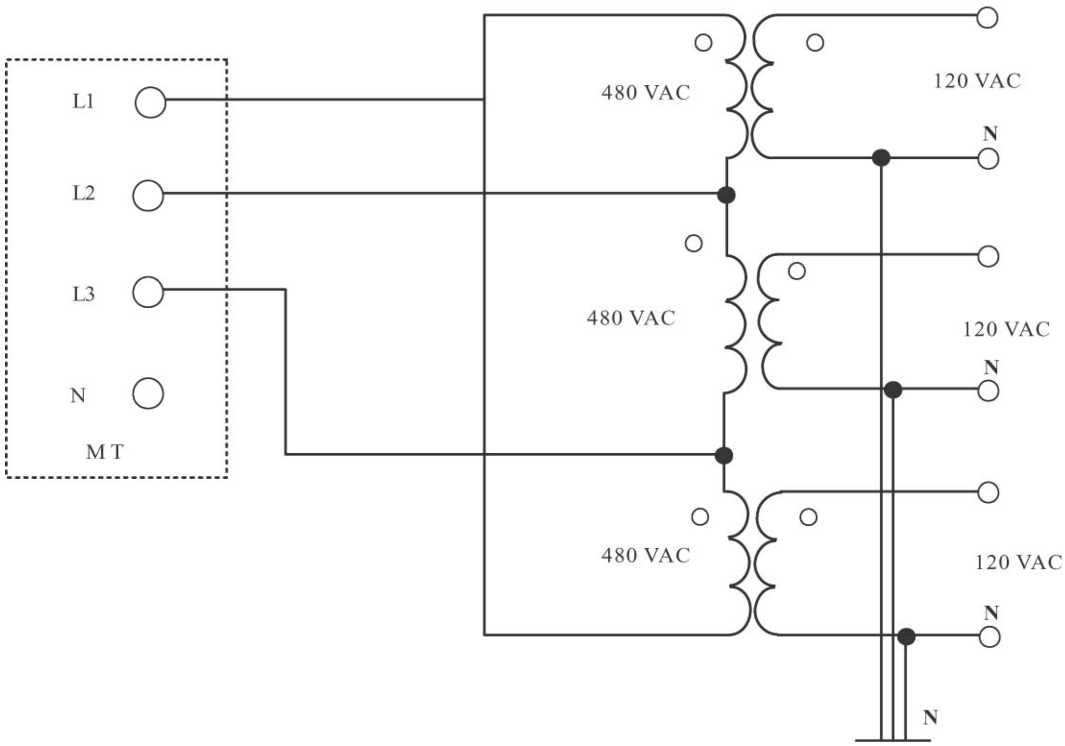


Figure 12-10. Full-Power Output via three (3) Isolated Single Phase Loads

Special Applications

Motor Control with Soft Start

In cases where the only connected load is a electric motor, the C1000 package inverter based power electronics may be used to avoid installation of a soft-start system.

Grid Connect Power Factor Correction

Future iterations of the MicroTurbine power electronics software will allow the setting of both reactive and active power. This feature may be useful in industrial applications where the correction of low power factors can avoid utility tariffs. Real power set-point maintains priority in cases of overload due to the vector sum of the reactive and active set-points exceeding MicroTurbine capacity. If your site is a candidate for this feature, contact Capstone applications.

Dual Mode Operation

A Capstone MicroTurbine can be used as an alternative power source to the grid, supplying a critical load. Automatic or manual load transfer from and to a utility source can be accomplished by either traditional auto-transfer switch, or by the Capstone Dual Mode System Controller (DMSC), serving as a transfer switch and also acting as intertie disconnect between the grid and the load. An intentional island will be created when load is balanced with the MicroTurbine output.

The critical load can be supplied from either:

- Power company grid (Line Power)
- Both, grid and MicroTurbine in parallel, Grid Connect (GC) mode
- The MicroTurbine, Stand Alone (SA) mode

The transfer is initiated automatically by:

- Undervoltage relay, built into the DMSC, in case of grid outage, or
- Manually, by operator on the DMSC front panel

In Grid Connect Mode (GC), a grid outage is detected by the DMSC undervoltage relay, which then isolates the utility from the MicroTurbine by opening the DMSC motorized switch. When the grid returns to normal operation, the DMSC will close the utility line circuit, supplying power to the load.

In Stand Alone mode (SA), the MicroTurbine solely supports the load, providing required voltage, active and reactive power.

Variable time settings accomplish coordination between DMSC and the MicroTurbine protection devices. In case a grid voltage sag is in excess of set time (from 0.2 to 10 seconds) and voltage (from nominal to 50%), the DMSC undervoltage relay will cause the DMSC switch to open, isolating the critical load and MicroTurbine from the grid. In case of a grid outage, the DMSC undervoltage relay will trip the switch immediately. In the latter case, the MicroTurbine protective relays will shut down the unit(s), transferring from GC to SA operations.

The DMSC will control an electromechanical disconnect device (such as an electrically operated circuit breaker) which can be installed at various locations and voltage levels. In the shown example, the disconnect device is specified for 208 V at the Meter (PCC), and the MT voltage is 480 V.

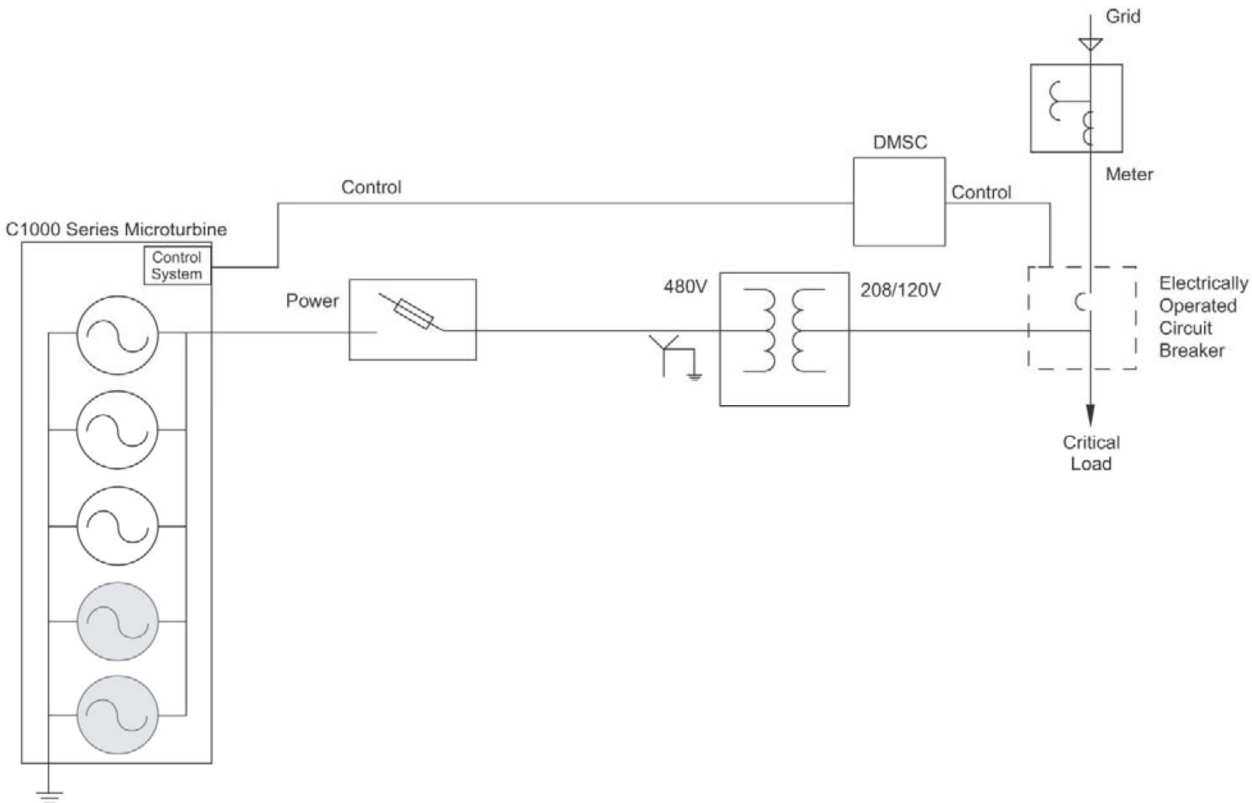


Figure 12-11. Dual Mode System Controller Connection Diagram

Power Meter Application

The MicroTurbine is a demand-loaded system. The demand can be established manually, or by closed loop signals produced remotely. At any point of a connected power system, meter data communicated to the MicroTurbine can be used to control real power.

In grid parallel applications with variable electric loads, there can be some restrictions for exporting electric power into the utility company grid. These restrictions can be related to non-power export mode or limited power export mode.

The MicroTurbine can accommodate meter data, forward power flow (+PWR) and reverse power flow (-PWR) in form of signals at a rate proportional to the power flow at the control point to control power produced. The application is called “Load Following”.

In processing the information, the MicroTurbine ramps up and down power output, keeping the required power level at the control point.

Power meters with KYZ outputs are commercially available from such vendors as Elster, Cutler-Hammer, GE, and Siemens.

Consideration shall be given to meters approved by the utility company for compatibility, when used at the Point of Common Coupling (PCC) or any other point controlled by the utility. In case of PCC, a meter can be rated and used as a revenue meter for accounting purposes.

Refer to Chapter 4: Operating Modes - Load Following and Chapter 10: Communications - External Power Meter Inputs in this document for more information.

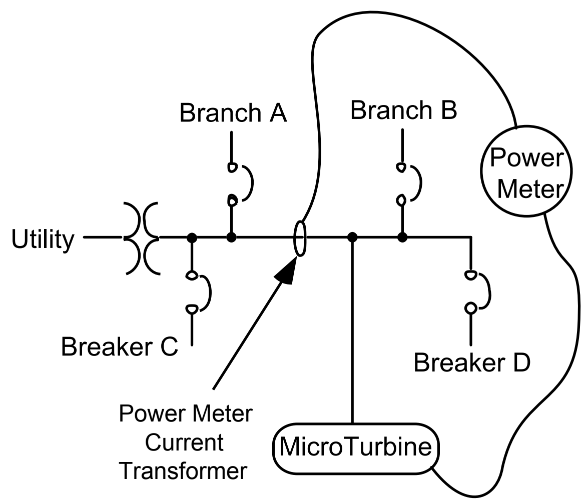


Figure 12-12. Power Meter Connection Diagram

Examples of Single Line Diagrams

The following illustrations are examples of single line diagrams.

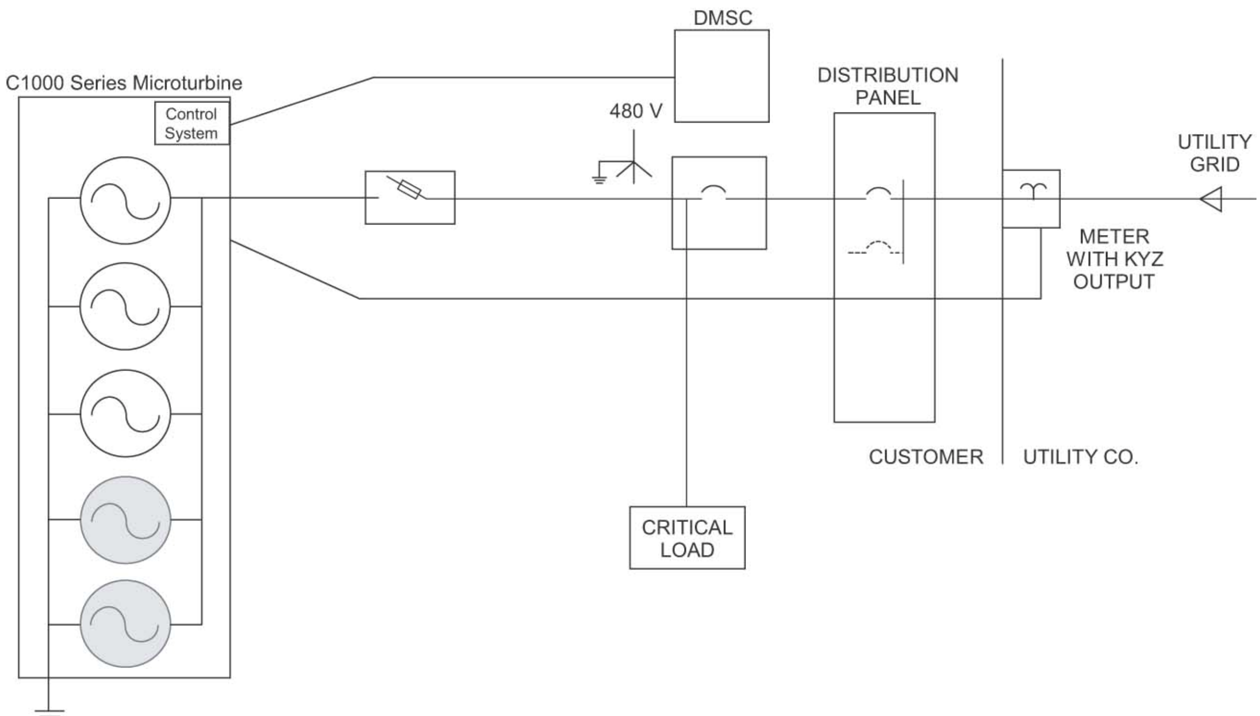


Figure 12-13. Single Line Diagram DMSC Example

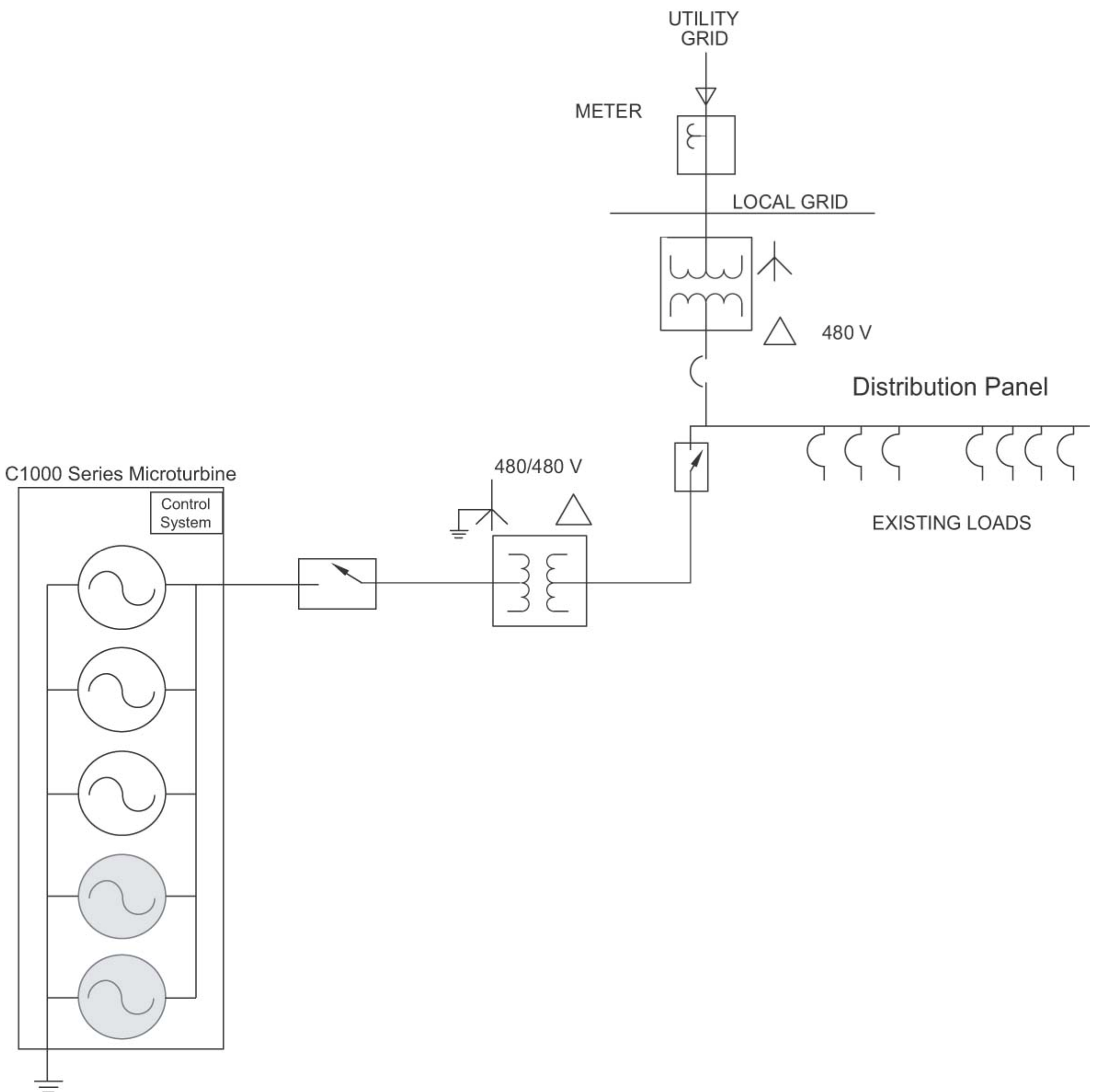


Figure 12-14. Single Line Diagram Grid Connect Example

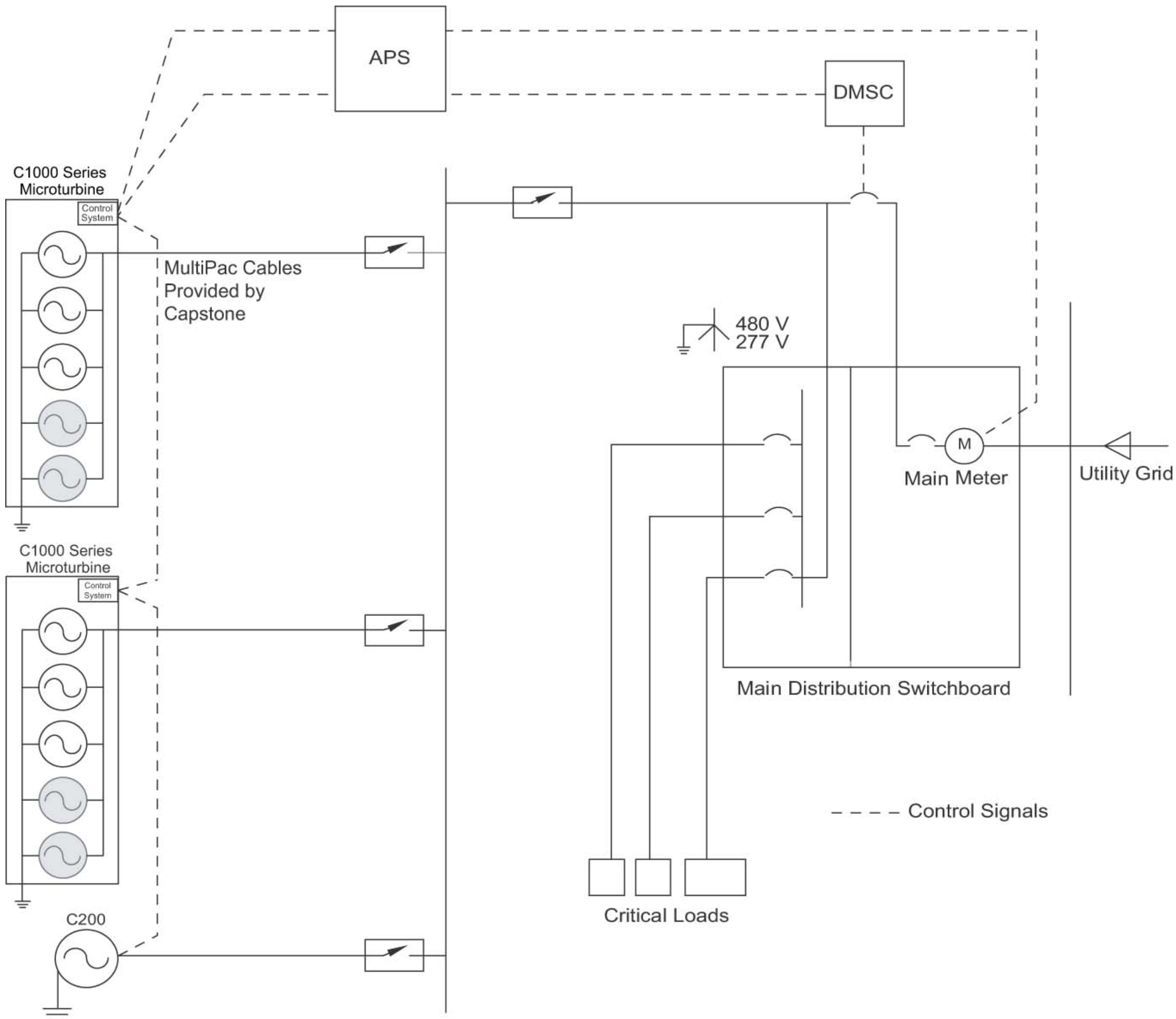


Figure 12-15. Single Line Diagram MultiPac Example

Utility Interconnection

Overview

Compliance with the requirements detailed in this document is essential to avoid problems that can affect the performance, life, reliability, warranty, and in some cases, the safe operation of the Capstone MicroTurbine system.

This section helps provide a standardized method for the interconnection of Capstone MicroTurbine generators to the power grid. It is intended for use by Capstone distributors, buyers, consulting engineers, and utility companies when considering MicroTurbines for utility grid parallel operations.

Due to technical advances in microprocessor-based power generation technologies with integrated relay protection functions, the Capstone MicroTurbine generator is designed to be easily interconnected to the electric utility grid, supplementing utility provided electric power.

This section is specifically written to assist with the applications of Capstone products. It provides an overview of the interconnection process, based on utility interconnect requirements, institutional standards (IEEE 1547, UL 1741), and individual states' interconnect standards.

Interconnect Application Steps

Feasibility Study

Economic analysis, precluding further steps, should consider local utility tariffs or competitive prices, interconnection fees, permit approval activities, and consulting services for Capstone applications. These expenditures vary depending on the number of the Capstone units, geographical location, and the utility company. It should be recognized that Capstone units are certified for safe utility interconnection by Underwriter's Laboratories and by the states of New York and California. This interconnect certification means that the process can take less time than for uncertified generators, and should therefore be less costly to customers.

Factors impacting the interconnect process:

- Number of MicroTurbine units proposed.
- Nature of the grid at point of connection.
- Power distribution or Point of Common Coupling (PCC) Voltage level.
- Requirements of the specific utility company.
- Electric Load to be supplied.
- Power Quality parameters such as voltage sagging, flicker, harmonic distortions.
- Other Distributed Generator or Generation (DG) systems operating on premises, in parallel with the grid.
- Utility and state regulations in the region.

Timeline

Though MicroTurbine installation and interconnection with a utility for parallel operation should not present technical difficulties, experience has shown that utilities are sensitive to interconnection issues, due to their legal obligation to provide power to their customers, and require a thorough, methodical approach consistent with individual utility requirements. Establishing realistic timeframes and duties will facilitate smooth implementation, maintain good relations, and minimize potential delays.

Utilities and states are currently standardizing the interconnection process, reviewing the fee structure and setting up testing requirements. The process will establish procedures, timelines and all requirements for interconnection with the grid.

Depending on the complexity of the installation, the time to complete the interconnection after the initial meeting varies from two weeks in some states (CA and NY), to six weeks in other states (TX). This is in part due to the complexity of the interconnection and individual utility requirements for protective relay functions. Since the Capstone C600, C800 and C1000 MicroTurbines have UL1741 certification, it is expected that in some cases the process can be 'fast tracked'.

Technical factors that can impact the interconnect review process or determine which utility interconnect plan applies include the following:

- Distribution System at the Point of Common Coupling (PCC): network or radial.
- Size of generation facility in relation to the capacity of the utility feeder.
- Export capacity, as a percentage of feeder or line section peak load.

The interconnection standards are issued in the following states:

- California (also known as CPUC Rule 21).
- New York (Standardized Interconnection Requirements and Application Process).
- Texas (PUCT DG Interconnection Manual).
- Ohio
- Alberta, Calgary Canada.
- Illinois (ComEd's "The DG Book").

Configurations

The electrical output of the Capstone MicroTurbine generator is 400 to 480 VAC 50/60 Hz, 3-phase, Wye, with a solidly grounded neutral. For other system voltages, transformation is required for MicroTurbine Grid Connect interconnection with the power system or to support Stand Alone operation with customer loads.

NOTE	MicroTurbines can be connected and operated with an asymmetric configuration, such as 120/240 VAC, 3-phases, 3 or 4 wires.

Project Design

A qualified engineering firm or a consultant, in compliance with local, state, and national codes and regulations, shall design an application which shall be in compliance with local, state, and national electrical regulations including the National Electrical Code (NEC). A one line diagram and a plan are minimally required in an interconnect application.

Interconnect Application

The typical application process consists of the following steps and can be more or less expanded based on state and utility requirements. Additional procedures can require additional screening and supplemental review, depending on the size of the DG application.

NOTE	Insufficient or incomplete information can cause a delay or rejection of the application.

- Initial Communication: inquiry for an application.
- Completion and submission of the Application forms, documents, and initial review fees.
- Upon acceptance, the utility company will prepare an Interconnection Agreement for execution by the applicant and the power company.

In addition, the following are normally required:

- A one-line diagram showing the electrical relationship and descriptions of the significant electrical components such as the primary switchgear, secondary switchboard, protective relays, transformers, generators, circuit breakers, with operating voltages, capacities, and protective functions of the Generating Facility, the Customer's loads, and the interconnection with the Utility Distribution System.
- Site plans and diagrams showing the physical relationship of the significant electrical components of the Generating Facility such as generators, transformers, primary switchgear/secondary switchboard, and control panels, the Customer's loads and the interconnection with the Utility Distribution System.
- Transformer information (voltages, capacity, winding arrangements, taps connections, impedance, etc.), if used to interconnect the Generating Facility with the Utility Distribution System.
- In the case of Dual Mode applications, it may be necessary to provide information on the transfer switching scheme or the Capstone Dual Mode System Controller, including capacity rating, technical and operational description.
- A disconnect device, with visible open circuit shall be provided and shown in the submittals, with specific brand, catalogue number, and rating, for each MicroTurbine output line, for utility company approval as a safety means for preventing any feedback to the grid during maintenance or repair work on the grid, upstream of the MicroTurbine.

Protective Relay Functions

The Capstone MicroTurbine is equipped with built-in relay protection functions, which are performed by a microprocessor and other firmware. These functions are described in the Protective Relay Functions section of this document, and are only adjustable by a Capstone Authorized Service Provider.

Additional protective relay functions may be required by the local utility, and can be installed externally when needed; for example a reverse power relay at the point of common coupling with the utility or a ground fault relay (device 51N).

Application Review by the Utility Company

The utility will conduct a review of the design package to ensure that the plans/design satisfy the goal of attaining a safe, reliable, and sufficient interconnection and will satisfy the technical requirements for interconnection. In addition, some site-specific tests may be required prior to final authorization to interconnect.

Interconnect Agreement

The utility will provide the executable standardized interconnection contract, metering agreement, and power purchase agreement, appropriate for the DG application and desired mode of operation. These documents will clarify roles and responsibilities between the utility and customer and specify any additional power systems modifications, metering, monitoring, or protection devices necessary to accommodate the DG project in the utility distribution system.

The agreements will establish responsibilities, completion schedules, and estimated or fixed price costs for the required work. Execution of these agreements will indicate approval to proceed with the installation or to perform the construction work related to the interconnection.

Start-Up and Tests

During the start-up process, a utility company may request a demonstration of certain capabilities related to parallel operation with the grid. Such a demonstration can include: a response to a grid outage, demonstration of relay protection functionality and settings, and a response to some grid anomalies such as loss of phase, which results in two- or one-phase conditions operating in a three phase distribution system. Non-export of power can be required in some installations, which can be demonstrated by enabling the MicroTurbine Load Following feature or using a separate reverse power relay.

In Dual Mode applications, islanding with isolated load and returning in parallel mode may be required to demonstrate and test the Capstone Dual Mode System Controller (DMSC).

These tests will require advance preparation including a written procedure and coordination with the utility.

CHAPTER 13: REFERENCED DOCUMENTATION

The following table lists applicable Capstone documentation.

Document Part No.	Description
400008	C200 User's Manual
400011	Advanced Power Server (APS) User's Manual
400023	Dual Mode System Controller (DMSC) User's Manual
400024	C1000 User's Manual
410002	Fuel Requirements Technical Reference
410013	CRMS Technical Reference, User Edition
410014	CRMS Technical Reference, Maintenance Edition
410073	CRMS-APS Technical Reference, Maintenance Edition
410074	CRMS-APS Technical Reference, User Edition
410065	Emissions Technical Reference
410071	Dual Mode System Controller Technical Reference
430073	C1000 Troubleshooting Guide
440000	Standard Maintenance Schedule
460051	C1000 Product Specification
480002	Landfill/Digester Gas Use Application Guide
480023	Advanced Power Server Technical Reference
480024	Advanced Power Server Installation Specification
524341	C1000 Outline and Installation (O&I) Drawing

APPENDIX A: C1000 MODBUS VARIABLE LIST

This Appendix provides the list of Modbus variables used for Modbus communication with the C1000 controller. Table A-1 gives the register where each variable is stored, the data identifier and description, the data type, units of measure expressed by the data, and the scale. The table also indicates whether the register is a read register, for customer data retrieval, or a write register for customer input. The display format for all variables is data format, and the size of each variable is one register.

Table A-1. C1000 Modbus Variables

Register	Data Identifier	Description	Data Type	Data Units	Data Scale	Customer R/W
40002	locked	Child Status with Respect to C1000 Controller	INT16	Number	1	R
40004	I_EXT_STRT	External Start Input	UINT16	Number	1	W
40005	I_SPIN_RSRV	Spinning Reserve Input	UINT16	Number	1	W
40097	pwrout	Output Power	INT32	Watt	1	W
40099	pwr_capacity	Power Capacity	INT32	Watt	1	W
40101	strcmd	Start Command	INT32	Number	1	R
40108	sys_utlcon	System Utility Connection Status	INT32	Number	1	R
40111	pwrdmd	Power Demand	INT32	Watt	1	R
40118	mpenab	MultiPac Status	INT32	Number	1	R
40701	batena	Battery Enable Flag	INT32	Number	1	R
40703	batchg	Battery Charge Flag	INT32	Number	1	R
40704	rchena	Recharge Enable Flag	INT32	Number	1	R
40705	DAQ_UNIT_LEQDATE	Date of Last Equalization Charge	UINT32	Time	Time Format	R
40711	DAQ_UNIT_BATTMP	Battery Temperature	INT32	Degrees Celsius	1	R
40712	DAQ_UNIT_BATSOC	Battery State of Charge	INT32	Percent (%)	0.1	R
40715	DAQ_UNIT_BATI	Battery Current	INT32	Amp	0.0488	R
40716	DAQ_UNIT_BATV	Battery Voltage	INT32	Volt	0.0488	R
40718	DAQ_UNIT_BATKW	Battery Power	INT32	kW	1.2207	R
40719	DAQ_UNIT_BATSTATE	Battery State	INT32	Number	1	R
42007	syscon	System Status	INT32	Number	1	R
42107	invpwr	Inverter Power	INT32	Watt	1	R

Table A-1. C1000 Modbus Variables (Cont)

Register	Data Identifier	Description	Data Type	Data Units	Data Scale	Customer R/W
42109	ia	Current Phase A	INT16	Amp	0.0625	R
42110	ib	Current Phase B	INT16	Amp	0.0625	R
42111	ic	Current Phase C	INT16	Amp	0.0625	R
42112	in	Current Neutral	INT16	Amp	0.0625	R
42113	va	Voltage Phase A	UINT16	Volt	0.0625	R
42114	vb	Voltage Phase B	UINT16	Volt	0.0625	R
42115	vc	Voltage Phase C	UINT16	Volt	0.0625	R
42161	genpwr	Generator Power	INT32	Watt	1	R
42203	engspd	Engine Speed	INT32	rpm	2	R
42165	contr_status	Contactor Status	UINT16	Number	1	R
42122	DAQ_UNIT_FREQ	Frequency	INT32	Hertz	0.0625	R
42123	DAQ_UNIT_PSVOLT	Power Supply Voltage	INT32	Volt	0.0625	R
42126	DAQ_UNIT_INVTMP	Inverter Heatsink Temperature	INT32	Degrees Celsius	1	R
42159	DAQ_UNIT_GENTMP	Generator Heatsink Temperature	INT32	Degrees Celsius	1	R
42201	DAQ_UNIT_PAMB	Ambient Pressure	INT32	psi	0.0625	R
42202	DAQ_UNIT_INTMP	Ambient Temperature	INT32	Degrees Fahrenheit	0.125	R
42206	DAQ_UNIT_TET	Engine Exhaust Temperature	INT32	Degrees Fahrenheit	0.125	R
42207	DAQ_UNIT_FULPCNT	Fuel Command	INT32	Percent (%)	0.1	R
42209	DAQ_UNIT_WARRHR	Operating Hours (formatted as low 4 byte - sends next byte as minutes and the high bytes as hours)	INT32	Time	Time Format	R
42211	DAQ_UNIT_WARRST	Number of Starts	INT32	Number	1	R
42213	DAQ_UNIT_RPM	Engine Speed	INT32	rpm	2	R
42215	DAQ_UNIT_FLTSSL _BASE	Severity Level of Highest Base Level Fault	INT32	Number	1	R
42217	DAQ_UNIT_FLTCODE _BASE	Fault Code of Highest Base Level Fault	INT32	Number	1	R

Table A-1. C1000 Modbus Variables (Cont)

Register	Data Identifier	Description	Data Type	Data Units	Data Scale	Customer R/W
44103	MultipacFrequency	Optimal MicroTurbine Communication Period	UINT32	Millisecond	1	W
44105	PingFrequency	Optimal Pinging Period while Seeking Unlocked MicroTurbines	UINT32	Millisecond	1	W
44107	DaqFrequency	Optimal DAQ Information Retrieval Period	UINT32	Millisecond	1	W
44109	MaxTurbineNumber	Maximum Turbine Number	INT16	Number	1	W
44110	I_GC_EN	Grid Connect Interconnect Flag	UINT16	Number	1	R
44111	I_SA_EN	Stand Alone Interconnect Flag	UINT16	Number	1	R
44112	I_BATSTRT	Battery Start Command	UINT16	Number	1	R
44113	I_STR_DMC	Dual-Mode Controller Start Command	UINT16	Number	1	R
44114	I_PWRMTR	Power Meter Input (Scale Determined by Transducer Type)	UINT16	Number	1	R
44115	I_MINCAP	Minimum Capacity Input (Scale Determined by Transducer Type)	UINT16	Number	1	R
44120	I_RTD	Temperature Sensor Input	UINT16	Degrees Fahrenheit	1	R
44121	I_RTDHIRES	Temperature Sensor Input (Hi-Res)	UINT16	Degrees Fahrenheit	0.1	R
44122	O_BATWAKE	Battery Wakeup Output Signal	UINT16	Number	1	R
44123	O_SALOAD	Stand Alone Load Output Signal	UINT16	Number	1	R
44124	O_MPWROUT2	MultiPac Power Output (High Word)	UINT16	Number	1	R

Table A-1. C1000 Modbus Variables (Cont)

Register	Data Identifier	Description	Data Type	Data Units	Data Scale	Customer R/W
44125	O_MPWROUT	MultiPac Power Output (Low Word) (combined with high word above to make MultiPac power output in Watts)	UINT16	Number	1	R
44126	O_MPWRCAP2	MultiPac Power Capacity (High Word)	UINT16	Number	1	R
44127	O_MPWRCAP	MultiPac Power Capacity (Low Word) (combined with high word above to make MultiPac power capacity in Watts)	UINT16	Number	1	R

APPENDIX B: C1000 CONTROLLER SCHEMATIC

This Appendix contains the schematic for the Dual Mode System Controller (DMSC). The DMSC schematic is shown in Figure B-1.

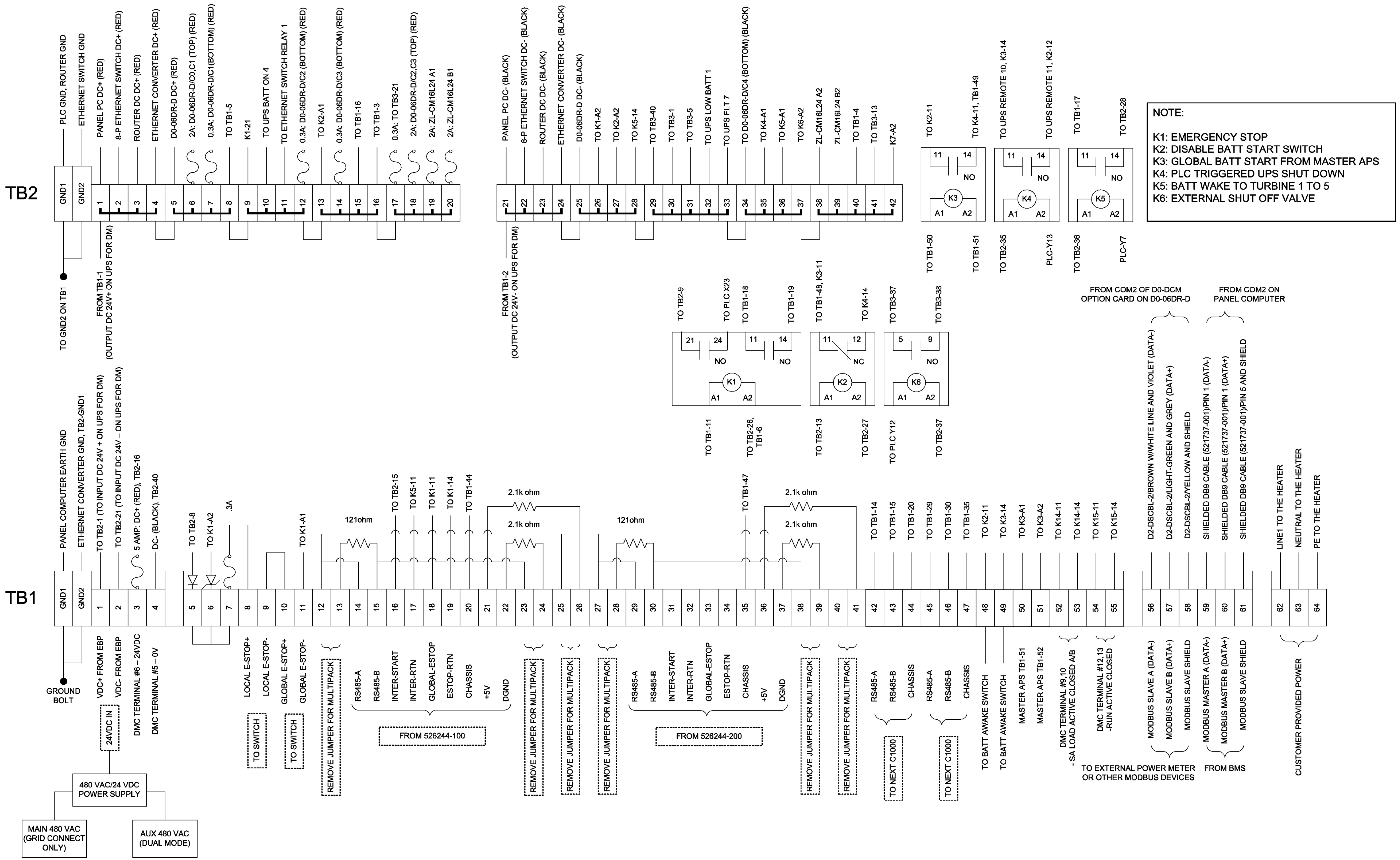


Figure B-1. C1000 Controller Schematic (Sheet 1 of 3)

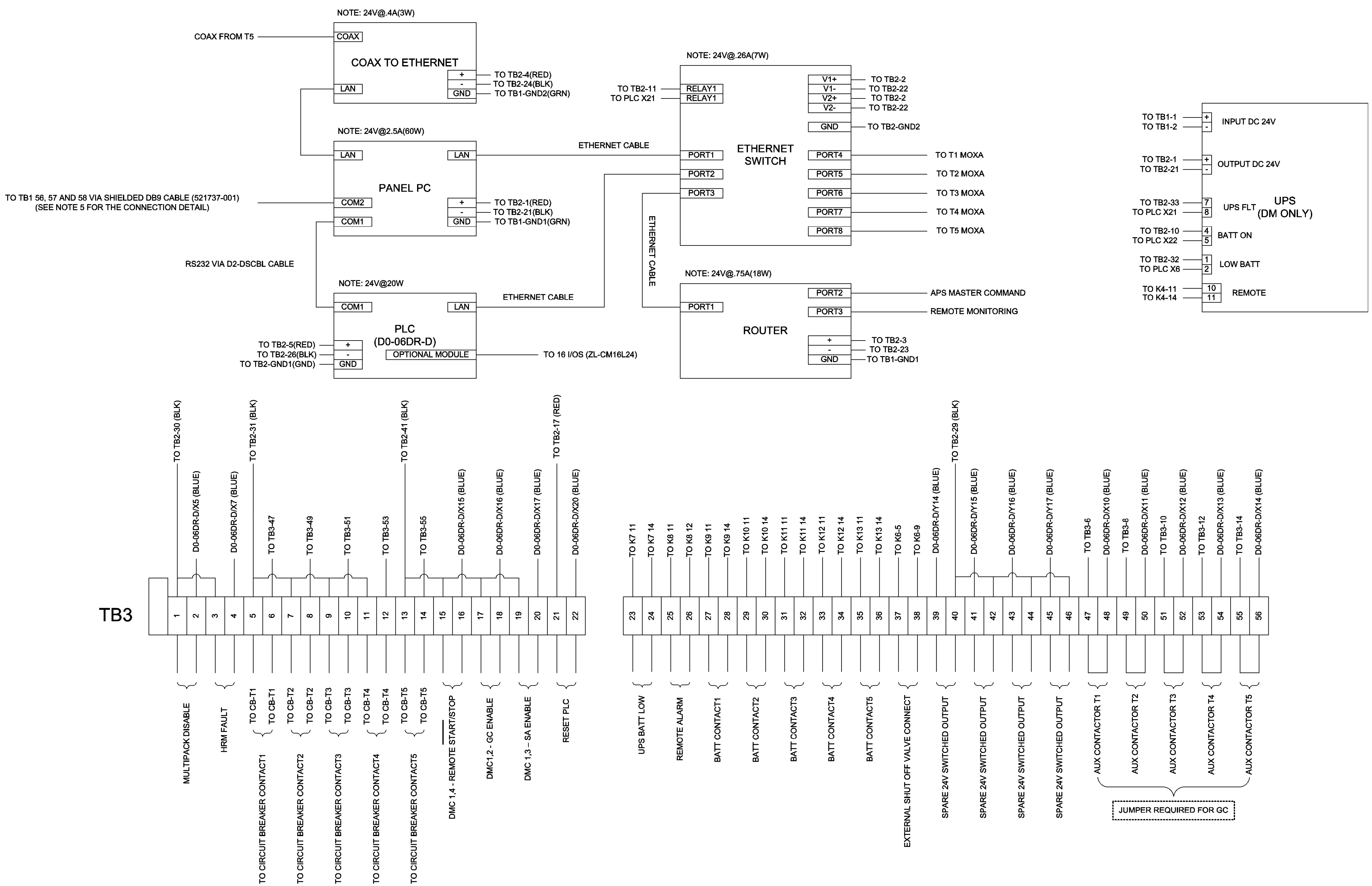
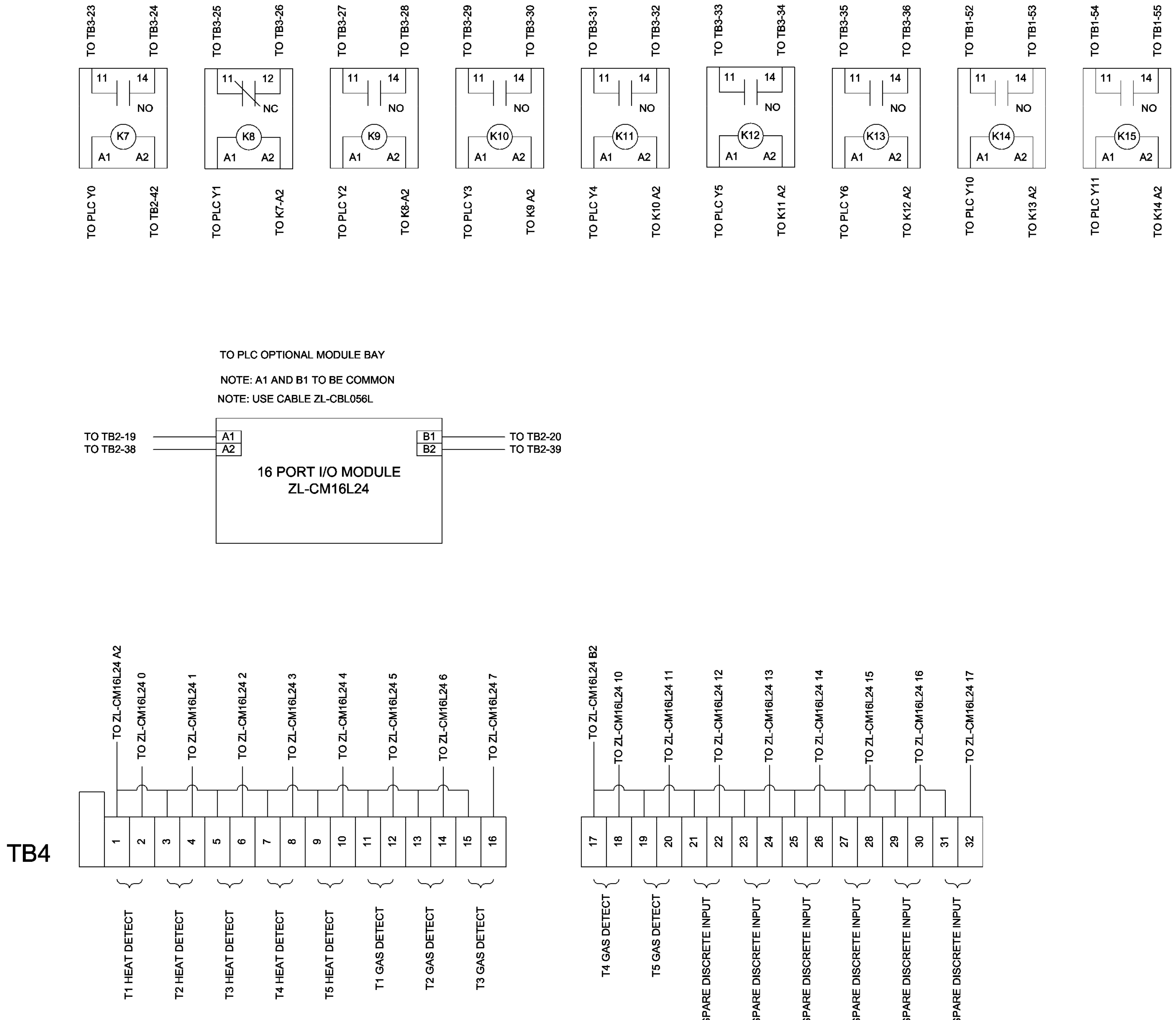


Figure B-1. C1000 Controller Schematic (Sheet 2 of 3)



NOTE:
K7: BATT LOW EXTERNAL
K8: REMOTE ALARM
K9: COMP1 BATT CONTACT
K10: COMP2 BATT CONTACT
K11: COMP3 BATT CONTACT
K12: COMP4 BATT CONTACT
K13: COMP5 BATT CONTACT
K14: DMC SA LOAD ACTIVE
K15: DMC RUN ACTIV CLOSED

Figure B-1. C1000 Controller Schematic (Sheet 3 of 3)